Gravitational Shielding Research

The following list of possible keywords relevant to the research of E.E. Podkletnov in the area of gravitational shielding can be implemented with a Web search algorithm to locate related documents on the Web and sort them by relevance.

Gravitational shielding theory and research

1. Podkletnov
    a. Variations:
        i. Yevgeni
        ii. Yevgeniy
        iii. Yevgeny
        iv. Yevgenij
        v. Eugene
        vi. Ye.
        vii. Ye.Ye.
        viii. Evegeny
        ix. Evgeniy
        x. Evgenij
        xi. E.
        xii. E.E.
2. Podkletnov Effect
3. Gravitational Meissner effect
    a. Variations
        i. Meissner effect
        ii. Gravitoelectromagnetic effects
4. Gravitational shielding
    a. Variations
        i. Gravity Shielding
        ii. Anti-Gravity Shielding
        iii. Gravitational screening
        iv. Gravitational force shielding
        v. Superconductor shield gravity
5. Anti-Gravity
    a. Variations
        i. Antigravity
6. Electrogravitics
7. London equation
    a. Variations
        i. Maxwell-London equations
8. Mass density
9. Weight reduction
10. Project Greenglow
11. Project Grasp
12. Tampere University of Technology

Related terms:

1. Electromagnetism
    a. Gravitational effects
    b. Maxwell equations
    c. Current density
    d. Electric charge
    e. Light velocity
    f. Permittivity
    g. Magnetic permeability
    h. Superconducting materials
    i. Electromagnetic dispersion
    j. Electromagnetic shielding
    k. Magnetic levitation
    l. Buoyancy correction
    m. RF Magnetron Sputtering
2. Mechanics
    a. Rotating machinery
    b. Flywheels
    c. Torque
    d. Angular momentum
    e. Rotational kinetic energy
    f. Levitating superconducting disks
        i. Disk rotation speed
        ii. Weight loss
        iii. Electrooptical balance system
3. Materials Physics
    a. Refractory materials
    b. Cerium compounds
    c. Indium compounds
    d. High temperature properties
    e. Electric conductivity of solids
    f. Porosity
    g. Thermodynamic stability
    h. Strength of materials
    i. Combustion
    j. Reduction
    k. Electroconducting ceramics
    l. Propane combustion
    m. N-type conductivity
    n. Mixed ceramics
    o. Cryostats
    p. Yttrium compounds
        i. Yttrium barium copper oxides
            1. $YBa_2Cu_3O_{7-x}$
        ii. Oxide Superconductors
    q. Copper oxides
    r. Ceramic materials
    s. Crystal structure
4. Boeing
    a. Phantom Works
    b. George Muellner
    c. Project Grasp
5. British Aerospace
    a. BAe
    b. BAe Systems PLC (U.BA)
    c. Project Greenglow
6. NASA
7. Tampere University of Technology
    a. Finland

Podkletnov's collaborators & other researchers

1. Buzea, C.Gh
    a. Institute of Technical Physics, Iasi, Romania
    b. Technical University `Gh. Asachi', Iasi, Romania
    c. Agop, M
    d. Nica, P.
2. Bass, Robert
    a. Journal of New Energy
3. de Podesta, Michael
    a. Bull, Martyn
    b. Birkbeck College, London , England
4. Akopov, F.A.
    a. Barykin, B.M.

    b. Novov, Yu.D.
    c. Pakhomov, E.P.
    d. Institut Vysokikh Temperatur RAN, Moscow, Russia (High Temperature Institute, Russian Academy of Science, Moscow)
5. Nieminen, R.
    a. Tampere University of Technology, Finland
6. Jaervinen, R.J.O.
    a. Vuorinen, P.T.
    b. Maentylae, T.A.
    c. Tampere University of Technology, Finland
7. Romanov, A.I.
    a. Valjano, G.E.
8. Modanese, G.
9. Unnikrishnan, C.S.
    a. Tata Institute of Fundamental Research, Bombay, India
10. Holwerda, Martin
11. Selin, Alexey

Publications

1. Journal of New Energy
2. Physica C: Superconductivity and its Applications
3. Journal of Crystal Growth
4. Proceedings of the Unified International Technical Conference on Refractories - UNITECR '89
5. Europhysics Letters
6. Physics Letters
7. American Institute of Aeronautics & Astronautics
8. Jane's Information Group
    a. Jane's Defence Weekly

Research Organizations

1. Tampere University of Technology, Finland
2. Institut Vysokikh Temperatur RAN, Moscow, Russia (High Temperature Institute, Russian Academy of Science, Moscow)
3. Tata Institute of Fundamental Research, Bombay, India
4. Institute of Technical Physics, Iasi, RomaniaTechnical University `Gh. Asachi', Iasi, Romania
5. Birkbeck College, London , England
6. Boeing
    a. A&M Systems
        i. Phantom Works
            1. Project Grasp
        ii. George Muellner
7. British Aerospace
    a. BAe Systems PLC
        i. Project Greenglow
8. NASA

Databases

1. Engineering Information
    a. Engineering Village 2
        i. Compendex
2. American Institute of Aeronautics & Astronautics
3. Jane's Information Group
    a. Jane's Defence Weekly
    b. Online Research
4. Yahoo Physics

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Dow Jones Business News

Boeing Attempting To Create Gravity-Defying Device - BBC

LONDON -(Dow Jones)- Researchers at the world's largest aircraft maker, Boeing Co . , are using the work of a controversial Russian scientist to try to create a device that will defy gravity, the BBC reported Monday on its Web site.

The BBC said Boeing is examining an experiment by Yevgeny Podkletnov, who claims to have developed a device which can shield objects from the Earth's pull.

Podkletnov is viewed with suspicion by many conventional scientists, but the involvement of Boeing has lent his work a new credibility, the BBC said.

The project is being run by the top-secret Phantom Works in Seattle, the part of the company which handles Boeing's most sensitive programs. The head of the Phantom Works, George Muellner, told the security analysis journal Jane's Defence Weekly that the science appeared to be valid and plausible.

Podkletnov says he countered the effects of gravity in an experiment at the Tampere University of Technology in Finland in 1992.

The scientist says he found that objects above a superconducting ceramic disc rotating over powerful electromagnets lost weight.

The reduction in gravity was small, about 2%, but the implications - for example, in terms of cutting the energy needed for a plane to fly - were immense, the BBC said.

Scientists who investigated Podkletnov's work, however, said the experiment was fundamentally flawed and that negating gravity was impossible.

But documents obtained by Jane's Defence Weekly and seen by the BBC show Boeing is taking Podkletnov's research seriously.

The hypothesis is being tested in a program codenamed Project Grasp. Boeing is the latest in a series of high-profile institutions trying to replicate Podkletnov's experiment.

The military wing of the U.K. hi-tech group BAe Systems PLC (U.BA) is working on an antigravity program, dubbed Project Greenglow.

The US space agency, NASA, is also attempting to reproduce Podkletnov's findings, but a preliminary report indicates the effect does not exist. -0-

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Monday, 29 July, 2002, 03:23 GMT 04:23 UK

Boeing tries to defy gravity

An anti-gravity device would revolutionise air travel

Researchers at the world's largest aircraft maker, Boeing, are using the work of a controversial Russian scientist to try to create a device that will defy gravity.

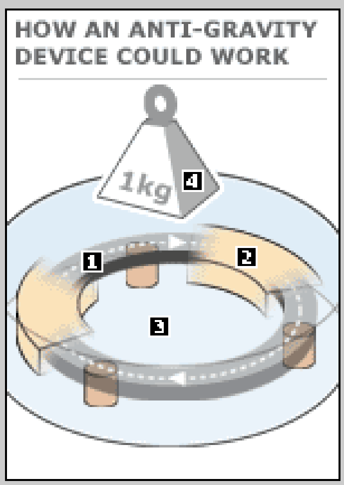
The company is examining an experiment by Yevgeny Podkletnov, who claims to have developed a device which can shield objects from the Earth's pull.

Dr Podkletnov is viewed with suspicion by many conventional scientists. They have not been able to reproduce his results.

The project is being run by the top-secret Phantom Works in Seattle, the part of the company which handles Boeing's most sensitive programmes.

The head of the Phantom Works, George Muellner, told the security analysis journal Jane's Defence Weekly that the science appeared to be valid and plausible.

Dr Podkletnov claims to have countered the effects of gravity in an experiment at the Tampere University of Technology in Finland in 1992.



1. Solenoids create magnetic field
2. Spinning, super-conducting ceramic ring
3. Liquid Nitrogen acts as coolant
4. Dr Podkletnov claims weight can be reduced by 2% (1kg=980g)

Q&A: What chance floating jumbos?

The scientist says he found that objects above a superconducting ceramic disc rotating over powerful electromagnets lost weight.

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The reduction in gravity was small, about 2%, but the implications - for example, in terms of cutting the energy needed for a plane to fly - were immense.

Scientists who investigated Dr Podkletnov's work, however, said the experiment was fundamentally flawed and that negating gravity was impossible.

Research explored

But documents obtained by Jane's Defence Weekly and seen by the BBC show that Boeing is taking Dr Podkletnov's research seriously.

The hypothesis is being tested in a programme codenamed Project Grasp.

Boeing is the latest in a series of high-profile institutions trying to replicate Dr Podkletnov's experiment.

The military wing of the UK hi-tech group BAE Systems is working on an anti-gravity programme, dubbed Project Greenglow.

The US space agency, Nasa, is also attempting to reproduce Dr Podkletnov's findings, but a preliminary report indicates the effect does not exist.

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Monday, 29 July, 2002, 14:52 GMT 15:52 UK

Q&A: Boeing and anti-gravity

The aircraft manufacturer Boeing is reported to be investigating anti-gravity research. But our science correspondent Dr David Whitehouse says jumbo jets are unlikely to start floating off the ground any time soon.

What has fired the interest of Boeing?

According to company documents seen by the respected journal Jane's Defence Weekly, Boeing is intrigued by the Russian of Russian Dr Eugene Podkletnov. It wants to see if it really is possible to build an "impulse gravity generator".

Boeing tries to defy gravity

What does Dr Podkletnov claim to have achieved?

He carried out an experiment involving a supercold, spinning ceramic ring.

Click here to see how an anti-gravity device could work

An object held above the ring lost about 2% of its weight. The pull of gravity on the object was reduced, he claims.

When did Dr Podkletnov do this?

It seems that the first time was at a Finnish university in 1992. However, the research paper that described the results was submitted to a scientific journal but then withdrawn. The same happened in 1996 when news of the paper's imminent publication leaked. However, Dr Podkletnov has continued to work on his ideas and is reported to have seen similar effects in his studies.

Has the experiment been repeated by others?

Several teams have tried but none has seen the same thing. The American space agency Nasa tried but said it couldn't find any effect.

Is anti-gravity possible?

The vast majority of the world's qualified scientists would fervently say that it is not. If it were possible to shield something from the force of gravity it would mean a rewrite of the most fundamental, cherished, and rigorously tested laws of physics. Most would put it alongside a perpetual-motion machine. That is, impossible.

But George Muellner of Boeing has been quoted as saying that the science of the antigravity device appeared to be valid

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and possible. Why did he say that?

There are three possibilities. Perhaps he knows something the rest of the world's physicists don't, or he does not understand the laws of physics, which would be highly surprising for a man in his position, or he has been misquoted.

If it were possible what would be the outcome?

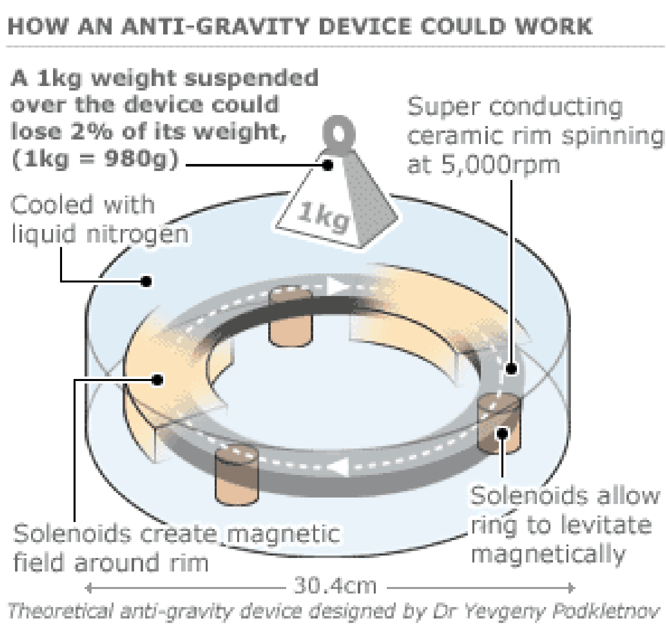
We could build spacecraft that would not need any rockets to power them. Aircraft would not need engines and could be any size and stay up indefinitely using no fuel. Supporters have claimed military and medical applications as well.

Have I heard this before?

If you read HG Wells, yes. In his First Men On The Moon, he writes of an eccentric inventor called James Cavor who creates a substance called Cavorite that repels gravity. Coating a capsule with it makes the vehicle fly up towards the Moon.

But is not history full of geniuses who changed the world after their colleagues had dismissed them as crazy?

There are not as many of these as you might think. Besides, just because a few geniuses have been laughed at in the past does not mean that every one who is laughed at today will turn out to be a genius in the future.



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Monday, 27 March, 2000, 23:34 GMT 00:34 UK

Gravity research gets off the ground

Such devices would shield planes from the Earth's pull

A leading UK company is challenging what we understand to be the fundamental laws of physics.

The military wing of the hi-tech group BAe Systems, formerly British Aerospace, has confirmed it has launched an anti-gravity research programme.

It hopes that Project Greenglow will draw scientists from different backgrounds to work on future technologies that will have echoes of the propellantless propulsion systems being investigated by Nasa's Breakthrough Propulsion Physics Program.

Bob Park, American Physical Society
This has zero chance of success
real 28k

Gravitation shielding

If any of the work is successful, it could lead to dramatic developments in the way we travel - anti-gravity devices could make it much easier for aeroplanes, spacecraft and even the next generation of cars to get off the ground.

In 1996, the experiments of a Russian scientist were jeered at by the physics world. Writing in the journal Physica C, Dr Yevgeny Podkletnov claimed that a spinning, superconducting disc lost some of its weight. And, in an unpublished paper on the weak gravitation shielding properties of a superconductor, he argued that such a disc lost as much as 2% of its weight.

However, most scientists believe that such anti-gravity research is fundamentally flawed. It goes against what we know about the physical Universe and is therefore impossible, they say.

Pascal's Wager

"I find it rather peculiar that they've done this," said Bob Park

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from the American Physical Society, in reaction to the BAe Systems admission. "One can only conclude that at the higher levels of these organisations there are people who don't have a very sound grounding in fundamental physics.

"You can invest a little money in far-out projects if they have some chance of success - it's called Pascal's Wager. In this case, most scientists would say there is zero chance of success."

Nonetheless, this view will not stop anti-gravity devices from continuing to be a popular feature of science fiction and the inspiration for countless websites.

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Monday, 27 March, 2000, 13:58 GMT 14:58 UK

British probe anti-gravity device

A British defence contractor, BAe Systems, has confirmed that it is funding research into a device which is said to modify the effects of gravity.

The concept was pioneered by a Russian physicist, Yevgeny Podkletnov, working in Finland, and employs electromagnets and a rotating disc.

Dr Podkletnov has said experiments showed that it eased gravitational force by two per cent or more, which could have a dramatic effect on means of travelling.

BAe Systems says it will call its anti-gravity research programme Project Greenglow.

However, the BBC Science Correspondent says the possibility that a basic law of physics can be altered has attracted ridicule from many scientists, who believe that the concept belongs in the realm of science fiction.

From the newsroom of the BBC World Service

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Friday, February 27, 1998 Published at 04:58 GMT

Despatches

Nigel Margerison
London

An international team of astronomers say they have found evidence that the universe is expanding at an accelerating rate which can only be explained by the existence of anti-gravity. Their findings are published today in the journal, Science. As the BBC's Nigel Margerison reports, if true, the data would challenge the current thinking on the history of space and time.

The accepted view up to now is that the birth of the Universe in the Big Bang catapulted matter outwards and the Universe has been expanding ever since. But physics decrees that the force of gravity will cause the acceleration to slow.

This new research shows that instead of slowing, the expansion is speeding up and that, say the scientists, can only be explained by anti-gravity, a force opposing the effects of gravity. The findings are based on data gathered from observatories around the world and the Hubble Space telescope.

Some of the most distant objects supernovae or exploding stars, up to 10bn light years from earth, were observed over a period of time and their speed of acceleration measured. Albert Einstein first proposed the concept of anti-gravity but later discarded the idea.

Even the scientists themselves can't believe their results saying they have looked for an error but so far can't find one. If no error is found scientists say the findings will mean the Big Bang happened longer ago than we thought and would mean that in billions of years time many of the stars we now see would have accelerated out of range, making the universe look a very lonely place.

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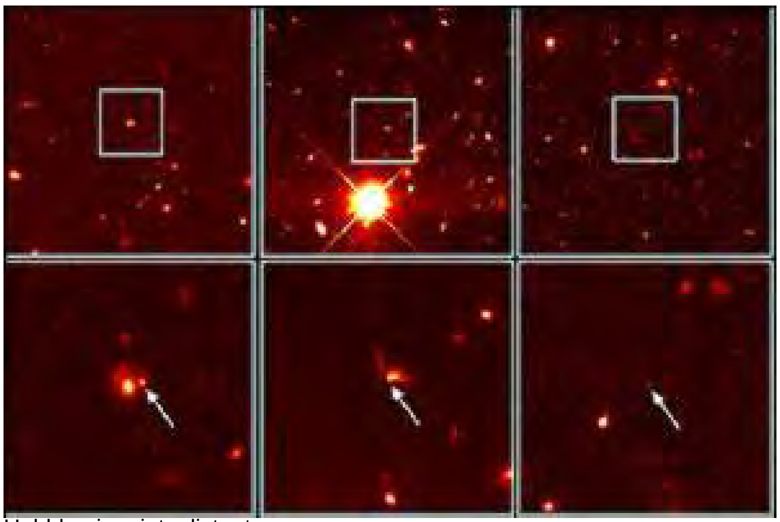
Friday, February 27, 1998 Published at 11:13 GMT

Sci/Tech

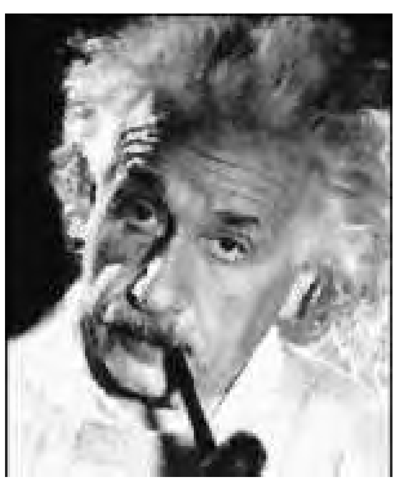
Universe's expansion speeds up



Hubble pinpoints distant supernovae

An international team of scientists has found evidence of a mysterious anti-gravity force that is causing the universe to expand at an accelerating rate.

The finding supports a concept first proposed by Albert Einstein, who later discarded the idea and called it his biggest blunder.



Einstein discarded his theory of anti-gravity

"It is such a strange result we are still wondering if there is some other sneaky little effect climbing in there," said Adam Riess, an astronomer at the University of California, Berkeley.

The 15-member team that made the discovery "have looked hard for errors," but found none, he said.

If true, the discovery could challenge the current thinking on the history of space and time.

Galaxies far, far away

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Einstein revealed

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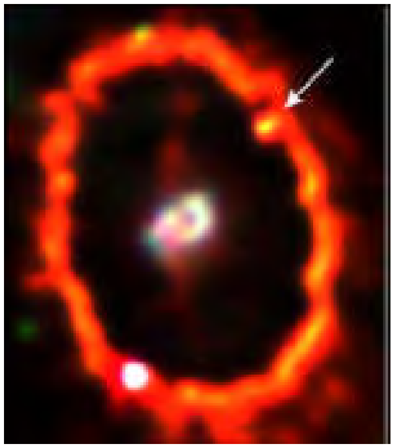
Journal of Science

Scientists say they discovered the force using the Hubble Space Telescope and ground-based telescopes in Hawaii, Australia and Chile while analysing the light arriving from 14 supernovae, or exploding stars, that are seven billion to 10 billion light-years from Earth.

A light-year is the distance that light travels in one year - about six trillion miles.



1997 photo of a supernova

The scientists expected to find that the expansion of the universe was slowing slightly from the effect of gravity. Instead, they say, it is actually speeding up.

One of the scientists involved, Robert Kirshner said the acceleration would continue and within billions of years many of the stars now seen would disappear from view.

"The universe will be a very different place to look at," he said. "It will be very lonely."

Questions answered

If the speed of expansion of the universe is accelerating, it could solve one problem for astronomers.

Some measurements have put the age of the universe at about 10 billion years. This is younger than the measured ages of some stars, a dilemma that has confounded astronomers.

With the acceleration of the universe factored in, the universe would have to be about 14 billion years old, some two billion years older than the oldest star, according to UC Berkeley's Mr Riess.

The team's conclusion will go through an intensive review by many astronomers before the results are accepted, according to Mr Kirshner. He noted however that preliminary results from a parallel study by another astronomy group agreed with the findings.

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Monday, 29 July, 2002, 20:53 GMT 21:53 UK

Russia's 'gravity-beating' scientist

Are anti-gravity devices science fiction or fact?

Aircraft manufacturer Boeing's work on an experimental anti-gravity device is based on a concept pioneered by Russian physicist Yevgeny Podkletnov.

BBC Monitoring looks back at his long and often controversial career.

Yevgeny Podkletnov was born into a highly educated family in the Soviet Union in the mid-1950s.

His father was a scientist and a professor in St Petersburg, while his mother had previously conducted research in the field of medicine.

Dr Podkletnov himself followed his father into a career in science, first earning a degree from the Mendeleyev Institute in Moscow, and then moving on to work at an institute within the Russian Academy of Sciences.

In the late 1980s, Dr Podkletnov left for Finland to pursue his research work at the Tampere University of Technology in Finland.

He first came to prominence in 1992, when he claimed to have conducted a successful experiment into what he called "gravity shielding".

Scepticism

Other scientists however, were initially unable to reproduce the results of Dr Podkletnov's experiment in their own laboratories, and the Russian scientist's research was viewed with considerable scepticism.

Undeterred, Dr Podkletnov submitted a paper on the research to the Institute for Physics in London. It was accepted for print, and was to be published in October 1996.

But, a month before that, news of his research entered into the wider public domain, when the Sunday Telegraph published an article highlighting the great potential for "anti-gravitation" technology.

The material for the article, which had been leaked, provoked a

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broadly negative reaction among the scientific community at large, and among Dr Podkletnov's research colleagues.

A week after the article appeared, Dr Podkletnov asked the Institute of Physics to withdraw his paper from publication.

Despite these problems however, major players have continued to maintain an interest in Dr Podkletnov's work.

Only in space are the effects of gravity ameliorated

In 2000, the British defence contractor BAe Systems confirmed that it would be funding research into a device said to modify the effects of gravity. And now Boeing, the world's largest aircraft manufacturer, is also using Dr Podkletnov's research in its own programmes.

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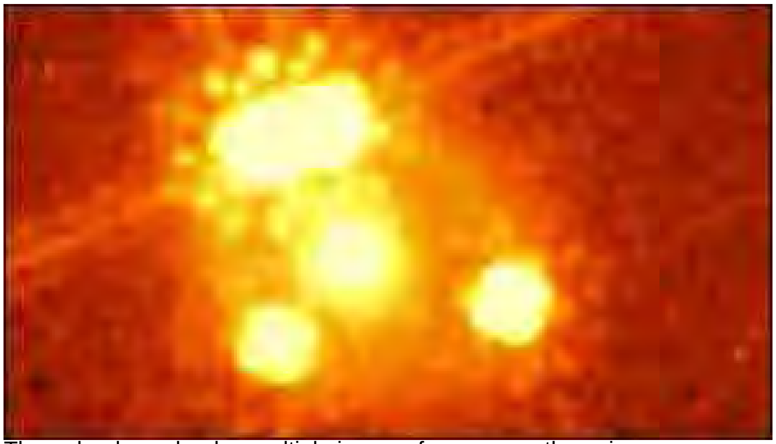
Tuesday, October 27, 1998 Published at 14:08 GMT

Sci/Tech

Hubble v Big Bang



Through a lens clearly - multiple images from across the universe

By our Science Editor David Whitehouse

New observations made by the Hubble space telescope suggest that some of our ideas about the Big Bang, the explosion that started the universe, may need revising.

A team from the University of Arizona has obtained a Hubble image of a distant galaxy, designated PG 115+080, seen through a much nearer galaxy.

PG 115+080 is eight billion light years away. The closer galaxy, three billion light years distant, acts as a 'gravitational lens' bending light so that the picture we see of PG 115+080 consists of several distorted images.

This is useful to astronomers because it gives them the chance to do some simple geometry to measure distances across the universe based on the path that the light in each image has travelled

The good news is that using the new Hubble image, it is possible to measure how fast the universe is expanding. The new figure agrees with previous estimates.

The bad news is that the big bang cannot easily explain this observed rate of expansion with the matter the cosmos seems to contain.

So it seems that the Big Bang theory needs patching up. There are three possible ways to do this but each adjustment is unpalatable to astronomers.

- They may have to change what they thought were the conditions in the big bang

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- They may have to postulate new, so far undiscovered, types of matter
- Or they may have to bring back an idea that Albert Einstein discarded.

Earlier this century, before it was discovered that the universe was expanding, Einstein tried to explain why it did not collapse. He came up with an anti-gravity force that holds it up.

When it was discovered in the 1920's that the cosmos expands, Einstein's new force was dropped. However some astronomers, while still not liking the idea, point out that it could come in useful today to explain a few things about the universe.

Despite these problems it is clear that the fundamental basis of the Big Bang theory, that the universe began in an explosion of time and space about 13 billion years ago, is not in dispute.

It is just that we do not understand what came next as well as we thought we did.

HEADLINES

Date Posted: July 29, 2002

JANE'S DEFENCE WEEKLY - JULY 31, 2002

Anti-gravity propulsion comes 'out of the closet'

NICK COOK *JDW Aerospace Consultant*
London

Boeing, the world's largest aircraft manufacturer, has admitted that it is working on experimental **anti-gravity** projects that could overturn a century of conventional aerospace propulsion technology if the science that underpins them - science that senior Boeing officials describe as "valid" - can be engineered into hardware.

As part of the effort, which is being run out of Boeing's Phantom Works advanced research and development facility in Seattle, the company is trying to solicit the services of a Russian scientist who claims he has developed 'high-' and 'low-power' **anti-gravity** devices in Russia and Finland. The approach, however, has been thwarted by Russian officialdom.

The Boeing drive to develop a collaborative relationship with the scientist in question, Dr Evgeny Podkletnov, has its own internal project name: 'GRASP' - Gravity Research for Advanced Space Propulsion.

A briefing document on GRASP obtained by *Jane's Defence Weekly* sets out what Boeing believes to be at stake. "If gravity modification is real," it says, "it will alter the entire aerospace business." The report was written by Jamie Childress, principal investigator for Boeing's propellentless propulsion work at the Phantom Works in Seattle.

GRASP's objective is to explore propellentless propulsion (the aerospace world's more formal term for **anti-gravity**), determine the validity of Podkletnov's work and "examine possible uses for such a technology". Applications, the company says, could include space launch systems, artificial gravity on spacecraft, aircraft propulsion and 'fuelless' electricity generation - so-called 'free energy'.

But it is also apparent that Podkletnov's work could be engineered into a radical form of weapon system. The GRASP paper focuses on Podkletnov's claims that his high-power experiments, using a device called an 'impulse gravity generator', are capable of producing a beam of 'gravity-like' energy that can exert an instantaneous force of 1,000g on any object - enough, in principle, to vaporise it, especially if the object is moving at high speed.

Podkletnov maintains that a laboratory installation in Russia has already demonstrated the 4in (10.16cm) wide beam's ability to repel objects a kilometre away and that it exhibits negligible power loss at distances of up to 200km (*JDW* 24 July). Such a device, observers say, could be adapted for use as an anti-satellite weapon or a ballistic missile shield.

The GRASP paper details the beam's reported characteristics: that it is immune to electromagnetic shielding, that it can penetrate any intermediate barriers (objects placed between the generator and the target), that it propagates at very high speed ("possibly light speed or greater") and that the total force is proportional to target mass - that its effect, in other words, is exactly the same as gravity's.

Podkletnov's claims first surfaced in 1992 when he published a paper detailing his low-power experiments into gravity-shielding using superconductors, materials that lose their electrical resistance at low temperatures. The original experiments were conducted at the University of Technology in Tampere, Finland, before moving to Russia.

Podkletnov, who has a PhD in materials science from Tampere and the University of Chemical Technology in Moscow, declared that any object placed above his rapidly spinning superconducting apparatus lost up to 2% of its weight.

Although he was vilified by traditionalists who claimed that gravity-shielding was impossible under the known laws of physics, the US National Aeronautics and Space Administration (NASA) went on to attempt a replication of his work in the mid-1990s.

Because NASA lacked Podkletnov's unique formula for the 30cm yttrium-barium copper oxide (YBCO) superconducting ceramic discs - a formula the Russian maintains is critical to the experiment's success - the attempt failed. NASA's Marshall Space Flight Center in Alabama will shortly conduct a second set of experiments, this time using apparatus built to Podkletnov's specifications.

In August 2001, Podkletnov published a paper revealing his experimental high-power work and it is this that forms the focus of the GRASP report. Boeing wants to build its own impulse gravity generator at Seattle but admits that it lacks vital knowledge in the area of the YBCO emitter - Podkletnov's special superconducting apparatus - which forms the heart of the generator.

As a result, Boeing recently approached Podkletnov directly, but promptly fell foul of Russian technology transfer controls. George Muellner, the outgoing head of the Boeing Phantom Works, confirmed that attempts by Boeing to work with Podkletnov had been blocked by Moscow, which is seeking to stem the exodus of Russian high-technology to the West. Muellner is convinced, however, that the science underpinning Podkletnov's work is real.

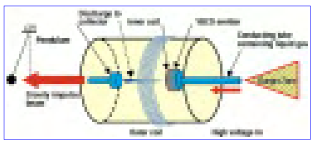
"The physical principles - and Podkletnov's device is not the only one - appear to be valid," he said. He confirmed that Boeing had conducted tests on a number of other **anti-gravity** devices, some of which were detailed in *JDW* 24 July.

"There is basic science there. They're not breaking the laws of physics. The issue is whether the science can be engineered into something workable," Muellner said.

The GRASP briefing document reveals that BAE Systems and Lockheed Martin have also contacted Podkletnov "and have some activity in this area".

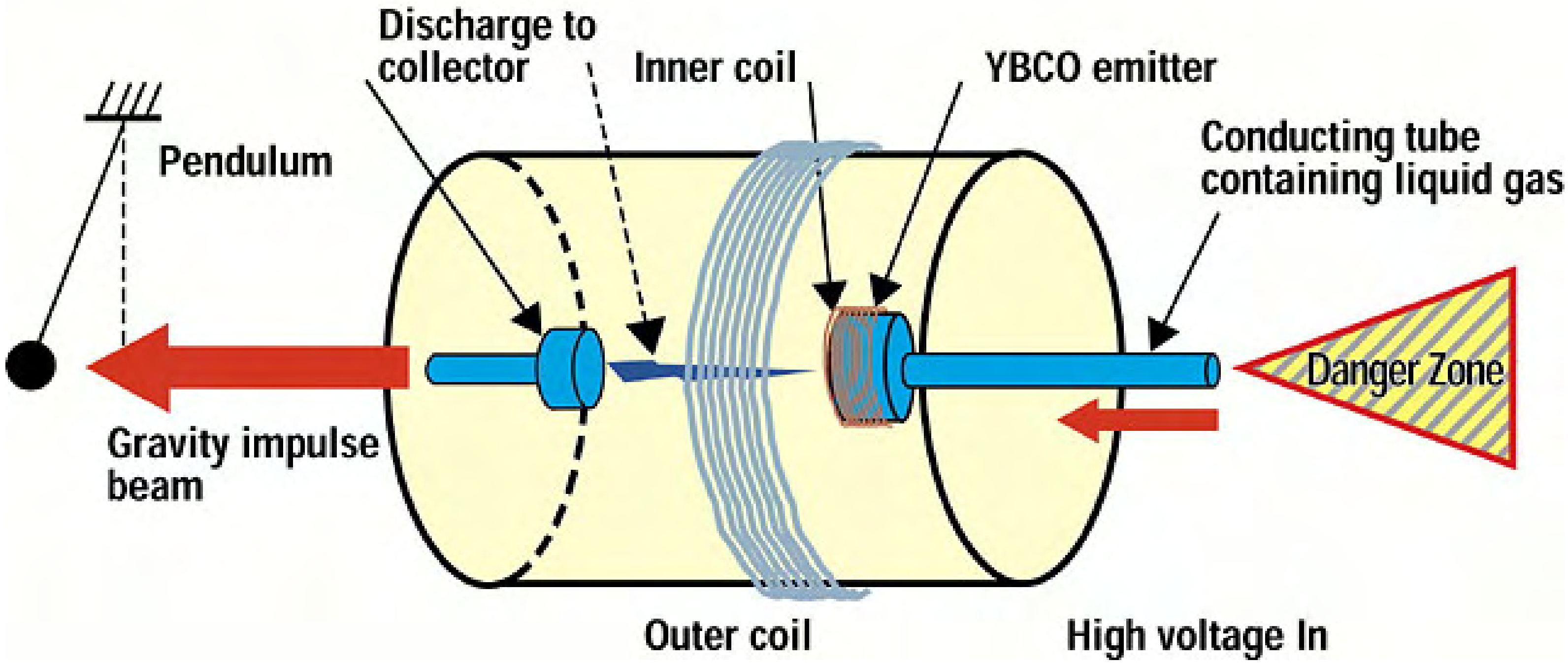
It is also possible, Boeing admits, that "classified activities in gravity modification may exist". The paper points out that Podkletnov is strongly anti-military and will only provide assistance if the research is carried out in the 'white world' of open development.

GRASP concludes that a "positive result from experiments would give Boeing a substantial advantage in the aerospace industry".



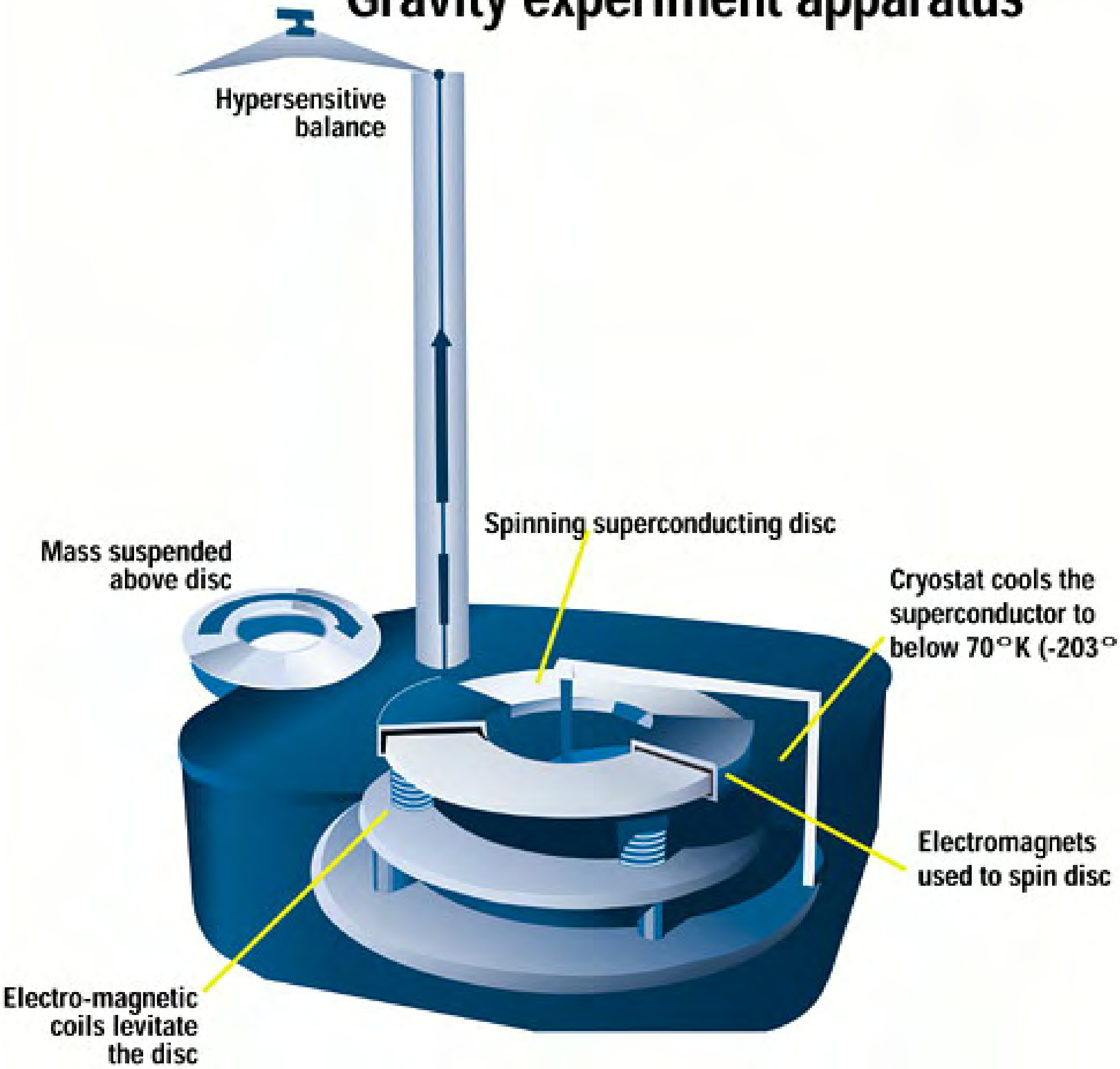
Reported operation of high-power gravity device: the YBCO emitter is cooled to superconducting conditions and the inner electric coil produces a magnetic field inside it. A very high voltage pulse is input to the emitter which then discharges to the collector. The discharge is guided and contained by the magnetic field in the outer coil
(Source: Jane's/Boeing)

Diagram showing configuration of low-power gravity modification experiment
(Source: Jane's/Boeing)



Discharge to collector
Inner coil
YBCO emitter
Pendulum
Conducting tube containing liquid gas
Danger Zone
Gravity impulse beam
Outer coil
High voltage In

Gravity experiment apparatus



FEATURE

Date Posted: July 18, 2002

JANE'S DEFENCE WEEKLY - JULY 24, 2002

Exotic propulsion: Air power ELECTRIC

NICK COOK *JDW Aerospace Consultant*
London

Intriguing, perplexing, confusing - projects in the field of 'anti-gravity' propulsion may seem the stuff of science-fiction but are very much the science-fact of today. Nick Cook looks at the research - and finds some high profile companies involved.

In July 2001, officials from a small Alabama-based research company called Transdimensional Technologies (TDT) - a concern with strong links to the National Aeronautics and Space Administration (NASA) - lifted the lid on a set of experiments they boldy claimed would "change virtually every aspect of our daily lives." Under laboratory conditions, TDT had just tested a tethered subscale model of a device it called the 'Lifter' that had demonstrated its ability to 'fly' using a propulsion methodology that science is grappling to explain.

The Lifter is the brainchild of TDT's chief scientist, Jeff Cameron, an electro-optics engineer by training, who had come by the idea after noticing some anamalous effects during his experiments with lasers. Sensing that the twisting motion of a foil and wire component within a part of the laser called a pre-ioniser was attributable to some unknown force, Cameron adapted the pre-ionising apparatus into a 3-D triangular shape with foil around its edges and a thin wire supported by balsa wood poles running above its upper surface. When positive and negative charges were run through the wire and the foil, the model Lifter levitated off the bench, making a crackling noise and spraying a colourful corona discharge.

By treating the triangular shape as a 'cell', TDT began scaling its Lifter, using increasing numbers of cells to make bigger and heavier 'craft'. Lifters have no moving parts and do not need to be aerodynamic in shape to get off the ground.

Soon after TDT published its findings, a French physicist, Jean-Louis Naudin, replicated the US company's experiments and quantified the lift produced. The biggest craft, the Lifter 4, used 36 cells joined together to form a basic hexagonal shape 820mm by 700mm in dimension. Constructed using the same materials as the TDT Lifters - aluminium foil, balsa wood and wire - Naudin's Lifter Version 4 weighed 32g and needed approximately 81W of power (40 kV at 2.01 mA) to levitate. To maintain stability in flight, it required 132.9W (44 kV at 3.02 mA). "The Lifter v4.0 is able to accelerate upwards very quickly and silently," Naudin reported, "and it is very stable during hovering." When word spread on the Internet of the TDT and Naudin tests, dozens of amateur engineers got in on the act. Using materials that can be found in hardware stores, they have consistently demonstrated that their lifters can and do 'fly' in and out of the laboratory.

It would be difficult for anyone to dispute the reality of lifters - films and still photos depict a plethora of lifter designs 'flying' on multiple websites. The $64,000 dollar question is: why are they flying at all? Some believe that their lift derives from an effect known as 'ion wind' - a 'breeze' caused by the movement of electrons crossing the gap between the wire and the foil. In 1964, Alexander De Seversky, founder of the Republic aviation company, patented a lifter-like design called the 'ionocraft' that relied on just such an effect for its postulated lift - but no such craft was ever built.

Although lifters can be steered by varying the power to the cells, the models are so light that if they are flown in the open they get blown around, even in a light breeze. What is needed, according to Graham Ennis, who organised the First International Field Propulsion Conference in Brighton, UK, last year, is for the effect to be tested on a 10m craft with a much higher voltage throughput - 10 or 20 times higher than the 20-45 kV typically applied to date. "The actual thrust is not linear. It increases by the square of the voltage. If you double the voltage you'll get four times as much thrust. To be effective, lifters not only need more voltages, but something hitherto not done: a very lightweight, very high voltage power supply," Ennis says.

TDT's Cameron admits that ion wind is generated by his company's Lifters, but it is far too slight, he says, to explain the levitational effect. If an obstruction is placed between the wire and the foil, thereby blocking the flow of electrons, the Lifter continues to levitate, he maintains. "We know enough about ion wind to determine how much is created and what it can push. There is insufficient ion wind to lift this test article." Tim Ventura, a Seattle-based lifter-builder, who has studied the phenomenon and the technology at length, is also sceptical that ion wind explains a lifter's ability to fly. "I think that ion wind is a component, but it's not the whole answer," he says. The question, however, remains. Is the lifter effect a laboratory curiosity or does it have some practical utility to aerospace development?

The TDT work has sparked further controversy via claims that it is not a new effect at all but a reworking of a phenomenon discovered by a US inventor called Thomas Townsend Brown in the late 1920s. Brown postulated a novel form of lift based on the assertion that an 'asymmetric capacitor' - a disc-shaped plate, slightly domed on one side, capable of retaining a large electrical charge - would experience thrust in the direction of its positive pole when charged negatively on one side and positively on the other. Intentionally or not, Cameron's Lifters are actually three dimensional representations of Brown's asymmetric plates, only on the lifters it is the air between the wire and the foil that acts as the capacitor.

In 1952, Brown went on to submit a proposal for a 'joint services' technology demonstration programme, 'Project Winterhaven', that was designed to lead to a M3 disc-shaped interceptor powered via his electro-kinetic propulsion principles. A series of tests demonstrated to the US Air Force in the mid-1950s, in which 3ft diameter disc-shaped capacitors were supposedly charged at 150 kV, were said by some contemporary sources to have exhibited results "so impressive as to be highly classified." Brown also fell victim to the claim that the 'Biefeld-Brown effect' was attributable to ion wind - a claim he sought to refute by demonstrating the ability of his capacitors to levitate in a vacuum. According to Ventura, lifters have also performed successfully under vacuum conditions. But ion wind or not - and, in a sense, proponents say, what does it matter, if it leads to an entirely new form of aero-propulsion - the lifter debate and Brown's work are attracting the attention of some high-profile organisations. Indeed, there are signs that after years on the shelf as a taboo science, electrogravitics - antigravity by another name - is under the microscope of government agencies and aerospace companies as they seek to find breakthrough propulsion technologies that could catapult aviation into a new era. The US Congress recently voted to give $4.75 million of US taxpayers money to the West Virginia-based Institute of Software Research (ISR) to see if its scientists could independently verify the bold claims being made for the lifters.

Earlier this year, NASA claimed it had discovered a "method for generating thrust from two dimensional asymmetrical capacitor modules" and filed US Patent No. 6,317,310 to register its 'breakthrough'. The space agency's observation that implementation of the patent would result in "potentially greater efficiencies and improved reliability over currently available electric thrusters" points to its manifest interest in the 'modules' as potential orbital transfer engines for satellites or other kinds of space vehicle. But in lodging the patent, NASA opened itself to a barrage of criticism from electrogravitic afficionados that it is patenting a discovery already made - and patented - by Brown a half century earlier. What is significant, however, is NASA's open acknowledgment of a form of thrust generation that neither it nor anyone else can adequately explain by known scientific principles.

NASA's quest for leap-ahead propulsion technologies was launched in 1996 under the Breakthrough Propulsion Physics (BPP) programme, run out of the NASA Glenn Research Center in Cleveland, Ohio. BPP is a subset of NASA's Advanced Space Transportation Plan (ASTP) managed by the NASA Marshall Space Flight Center in Huntsville, Alabama. ASTP's wide-ranging remit was to scout out bold-strokes technologies designed to lead to visionary forms of space propulsion that in the near term could reduce the cost of space access and within 100 years or so, as the project evolved, lead to true quantum leap propulsion advances capable perhaps of taking man to the stars. Under BPP, NASA Glenn was handed a remit to fund research into emerging principles that might lead to forms of propulsion hitherto regarded as impossible.

For example, it has been looking at ways of overcoming the supposedly unbreachable light-speed barrier as well as the manipulation of poorly understood physical forces such as gravity and inertia.

Despite its public appeal and relative low-cost - a total budget over seven years of $1.7 million - BPP was notified at the end of June that its funds were being cut and diverted into nearer-term NASA space-launch and propulsion research. Although BPP may still be resurrected - attempts are being made to 'park' it into a non-profit institute that could be configured to receive funds from other government agencies or industry sponsors - the outlook, according to officials close to the programme, is not good. BPP, they say, has ended up a "collateral casualty" of fallout from an investigation by the Office of Management and Budget (OMB) into what OMB has perceived as overlapping research by NASA Glenn, NASA Marshall and the ISR in 'breakthrough' areas of propulsion physics.

Among other criticisms, according to Marc Millis, who founded the BPP programme, OMB objected to the amount of funding that had been devoted to the testing of claims that gravity may be 'shielded' to produce a levitation effect. This task, though related to the BPP effort, was actually pursued as an in-house effort by NASA Marshall, which from 1996 has been seeking to verify claims by a Russian materials scientist that objects can lose their weight by up to 5% when placed above superconducting ceramic discs rotated at high speed. The scientist, Dr Evgeny Podkletnov, discovered the effect while working at the University of Tampere, Finland, in the early 1990s. When he published his claims, however, he was vilified by traditionalists who said that 'gravity shielding' was impossible.

But Podkletnov has demonstrated to the satisfaction of many that some kind of weight reduction effect is taking place and with its obvious potential utility in reducing launch weights - and therefore launch costs - NASA Marshall quickly registered its interest. It had already been approached by a researcher at the University of Alabama in Huntsville, Ning Li, who independently claimed that she could produce a 'gravity-like field' capable of repelling or attracting matter using rapidly spinning superconductors, materials that lose their electrical resistance at low temperatures. In the mid-1990s, NASA Marshall unsuccessfully tried to replicate Podkletnov's experiments, but without the Russian scientist's unique formula for his 30cm yttrium-barium copper oxide superconducting discs, the agency admitted it was largely operating in the dark. In 1999, it paid $600,000 to a Columbus, Ohio, company called Superconductive Components (SCI) to construct discs like the ones Podkletnov had been using in Russia and Finland and Podkletnov was hired as a consultant. After some delay, it is expected shortly to take delivery of SCI's superconducting apparatus. Ron Koczor, who heads up the programme at NASA, is confident that the experiment will go ahead, despite the OMB's investigation into what it sees as wasteful and unnecessary duplication of US government-funded research.

Li and Podkletnov have continued with their work. While Li has gone to ground, apparently to produce a workable derivative of her 'AC gravity machine' - which, she says, will be able to produce a beamed, 'gravity-like' force in any direction - Podkletnov, now based at the Moscow Chemical Scientific Research Centre, has taken his ideas further, publishing claims - backed by an Italian physicist, Giovanni Modanese of the California Institute for Physics and Astrophysics and the University of Bolzano, northern Italy - that he has developed what he refers to as an 'impulse gravity generator' capable of exerting a repulsive force on all matter.

Using a two- to 10-million Volt power supply developed recently in Russia - it is, significantly, Podkletnov says, no bigger than a fridge - a strong electrical discharge source and a rapidly rotating superconductor, Podkletnov's equipment has produced a 'gravity impulse', he claims, "that is very short in time and propagates with great speed (practically instantaneously) along the line of discharge passing through different objects without any observable loss of energy".

The result, he maintains, is a repulsive action on any object the beam hits that is proportional to its mass. Using a laser pointer, Podkletnov says that his 'laboratory installation' has demonstrated its ability to knock over objects more than a kilometre away.

"Our theoretical studies give grounds to claims that the gravity impulse will have negligible power loss at a distance of up to 200km when propagating through air and space," he adds. He is already proposing practical applications of the device. "Even our laboratory-scale installation, when combined with a precise modern radar system gives us a possibility to change the trajectories of satellites". While there are no independent verifications of Podkletnov's claims, the fact that his work is being taken seriously by NASA, at least, should lend some credence to them, proponents say.

Podkletnov says that his impulse gravity generator could be engineered into a radical new form of aero-engine, but it is also apparent that it could be developed into a new form of weapon - one that could knock satellites from their orbits or ballistic missiles from their impact trajectories. *Jane's*

Defence Weekly understands that one US aerospace company - Boeing - could already be working on a derivative of Podkletnov's impulse generator. Boeing admits that its Phantom Works advanced projects division "is aware of Podkletnov's work on an impulse gravity generator and would be interested in seeing further development work being done."

The company, however, may have already taken steps towards assembling a device - possibly under classified auspices. Informed sources maintain that it has proposed a 'gravity modification experimental setup' using a superconducting disc housed in a stainless steel vacuum chamber and linked to a 3 mV Van de Graaff generator. The sources told *JDW*: "Some preliminary work has been done by Boeing in assembling the electrical part of the 'gravity gun', but the company still has a problem with the superconducting emitter." The claims and the company's response to them show, if nothing else, that Boeing, like NASA, is engaging in new and little-understood areas of physics in attempts to develop a fundamental understanding of phenomena that could lead to breakthroughs.

Boeing denies that it is funding "any activities" in this area, but it declined to be interviewed on any aspect of its interest in Podkletnov's work - or its other '**anti-gravity**' type research projects. One of these was well documented in a publication called 'Infinite Energy', which reported that the Phantom Works ran tests in late 1999 of a 'two-rotor reactionless drive unit' built by a California-based inventor called Robert Cook. The tests were led by Jamie Childress, 'principal investigator' in this field for the Phantom Works in Seattle. On 29 November, 1999, the magazine reported, the reactionless drive unit "proved itself by accelerating a series of 5lb weights from zero to over 1,000ft per minute in a fraction of a second and then decelerating them without producing the 90 to 100lb negative reaction force required by Newton's Third Law of action-reaction." The Cook Inertial Propulsion (CIP) engine uses a pair of counter-rotating arms spinning about a common axle to convert centrifugal force into linear force. By adding additional rotors, Cook says that he can markedly increase the thrust.

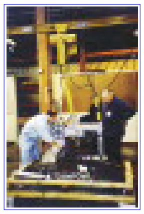
The reason for Boeing's interest in the CIP and Podkletnov's impulse gravity work remains unclear, but it is apparent, just as it was in the mid-1950s - when Convair, Martin and other US aerospace companies revealed their deep involvement in gravity-led research programmes, then fell silent on the subject - that a quest for radically alternative propulsion methodologies is firmly rooted in its agenda.

TDT's basic, single triangular cell Lifter photographed using light-enhanced photography shows the device's electrical corona - a side-effect of high-voltage charge transfer
(Source: American Antigravity)

TDT's third Lifter measures 1m on each side and generates lift through four triangular cells
(Source: American Antigravity)

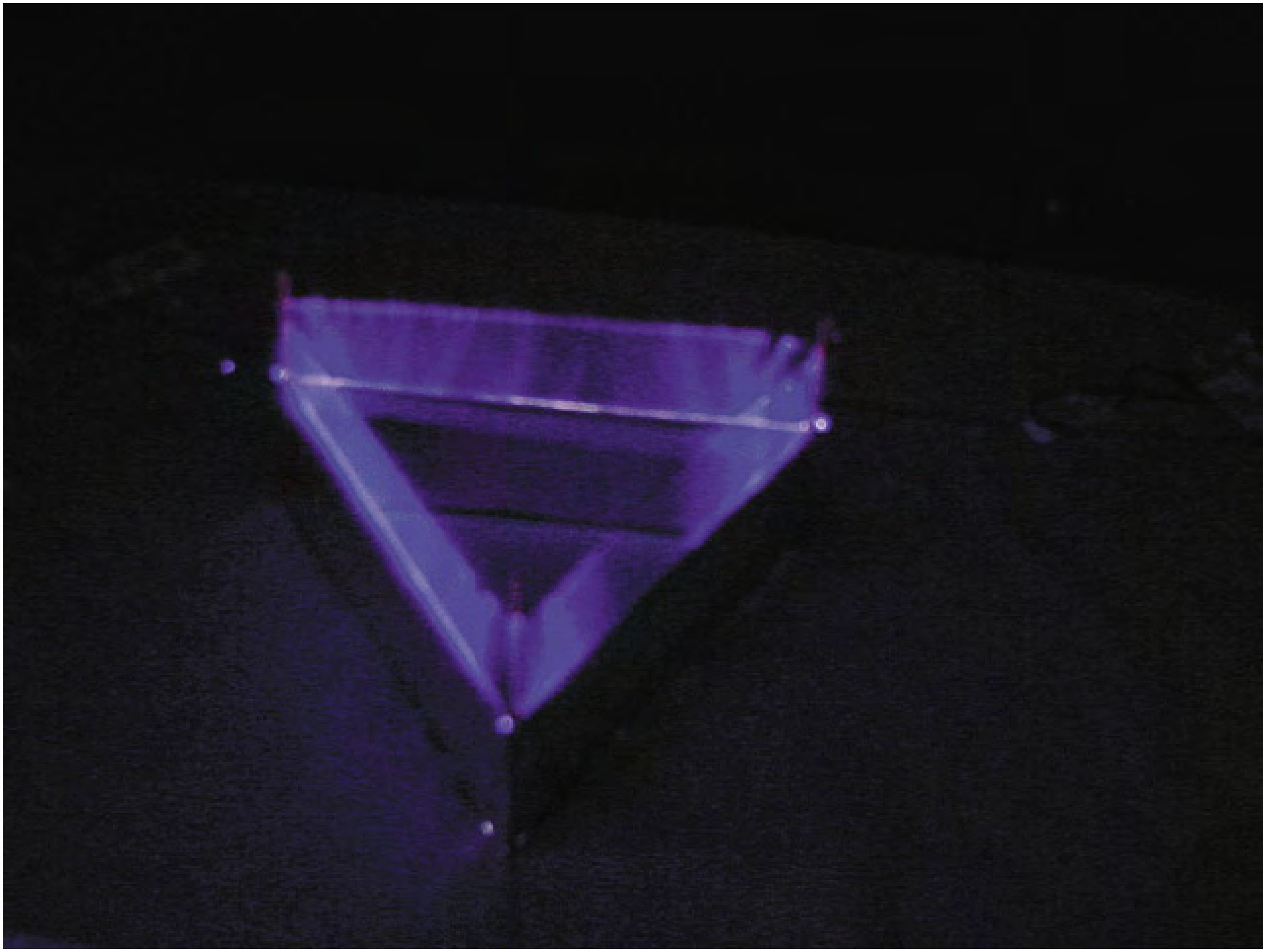
Close-up of Lifter 3 in flight at TDT's laboratory in Alabama
(Source: American Antigravity)

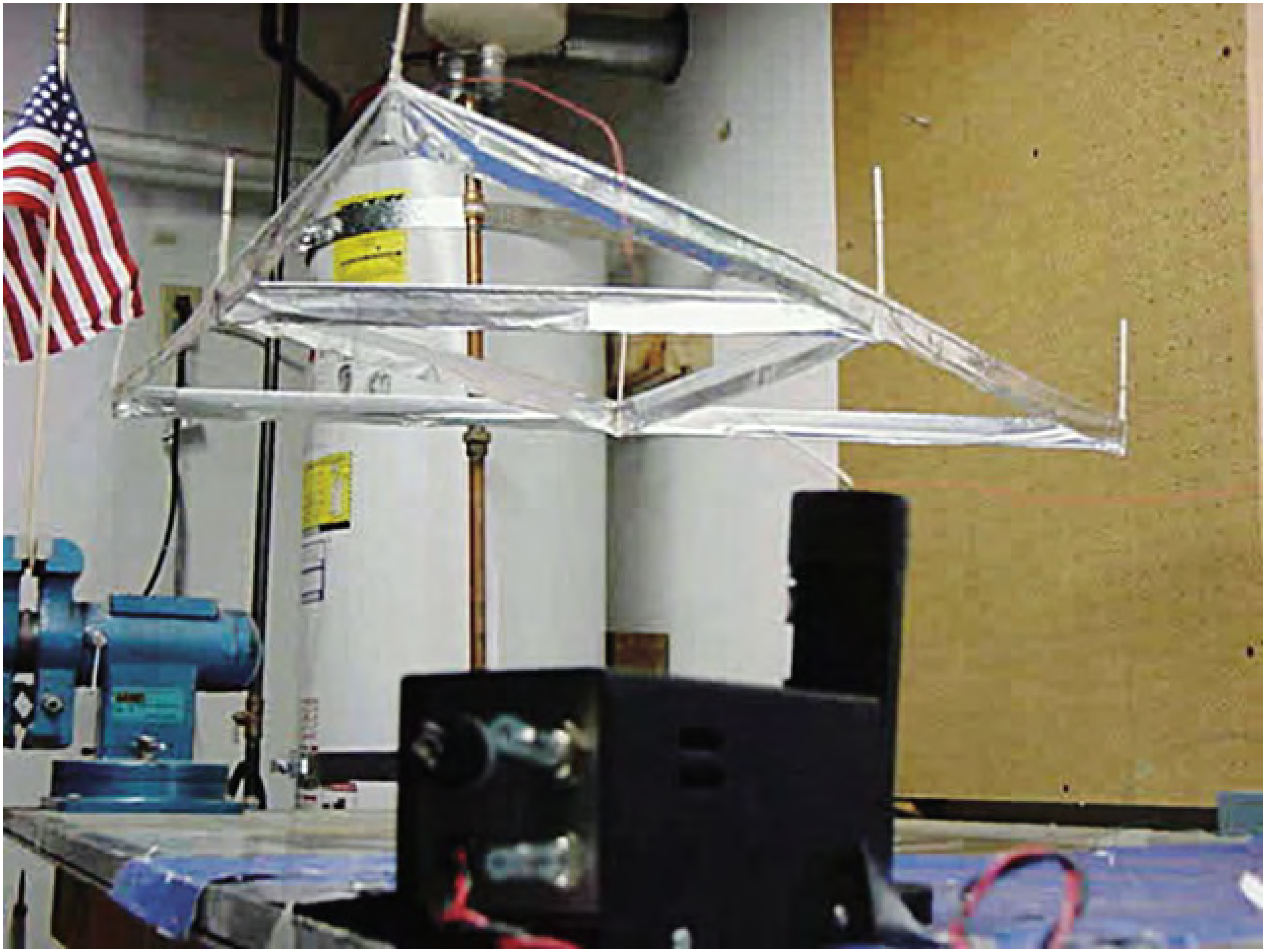

The Cook Inertial Propulsion unit being prepared for a strain-gauge test at Boeing's facility in Seattle
(Source: Boeing)

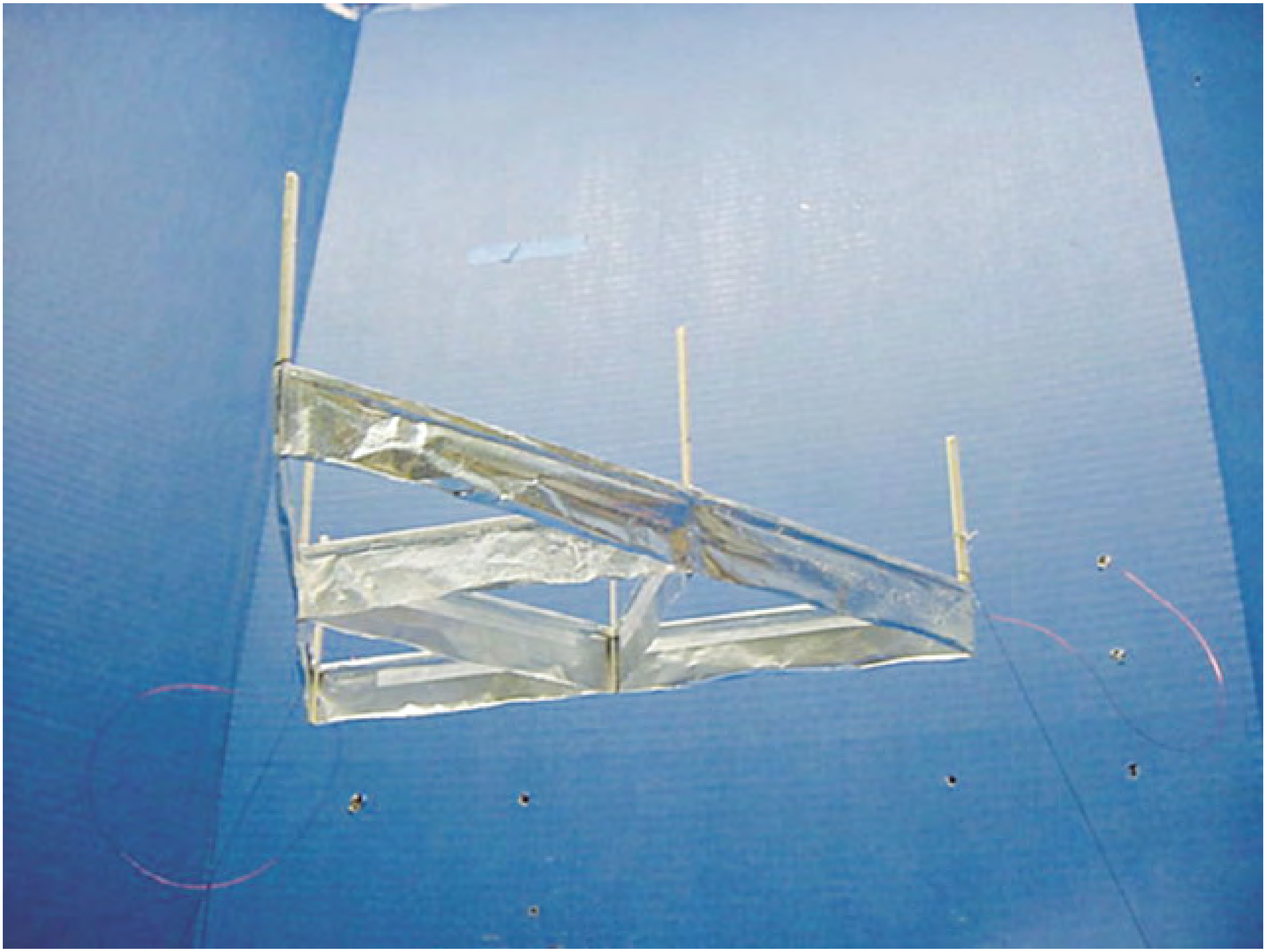

Californian inventor Robert Cook, right, pictured at the tests of his inertial propulsion system by Boeing
(Source: Boeing)

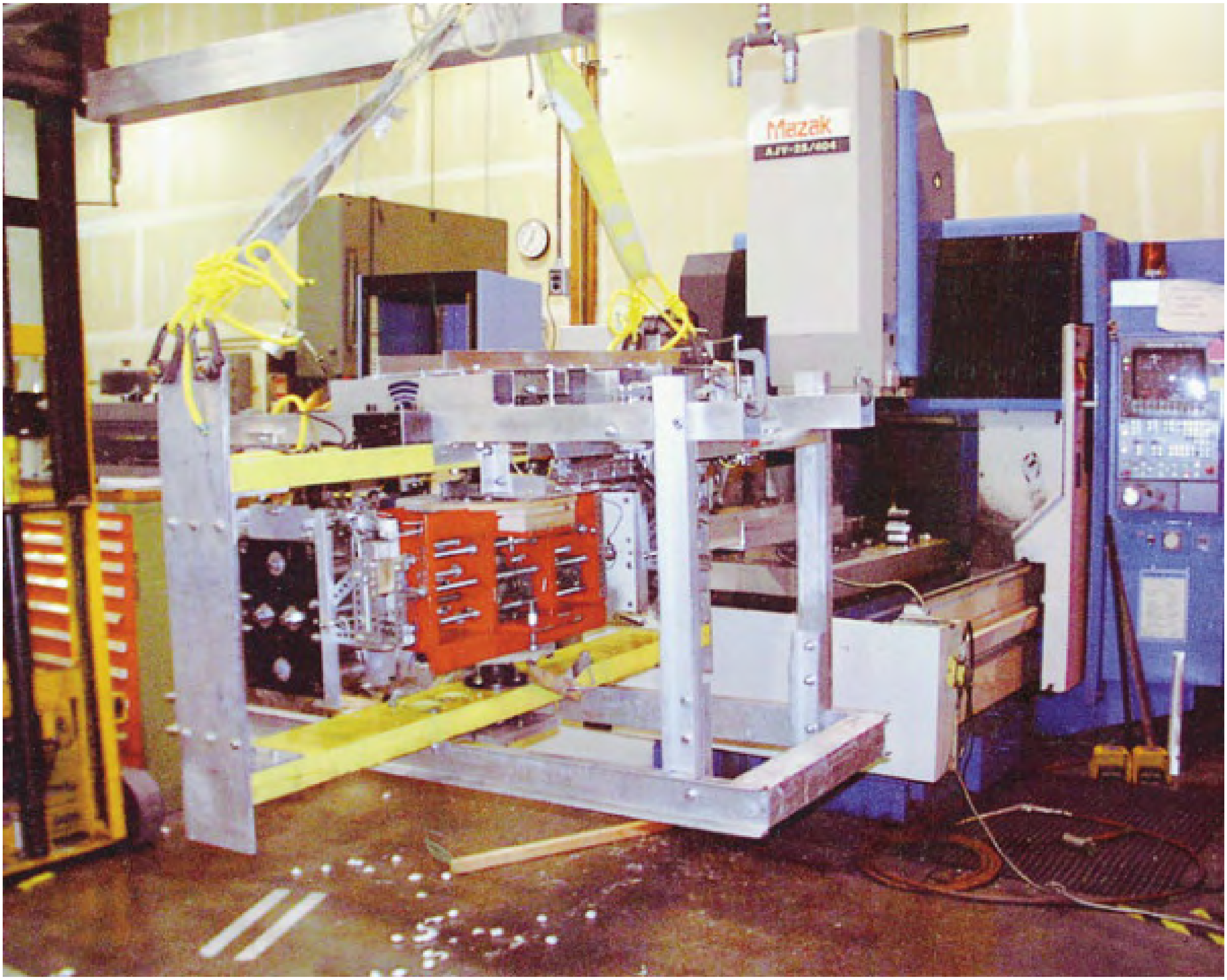

Boeing's stainless steel vacuum chamber proposed for the Podkletnov experiments
(Source: Boeing)


Boeing's Van de Graaff generator proposed for the Podkletnov experiments
(Source: Boeing)





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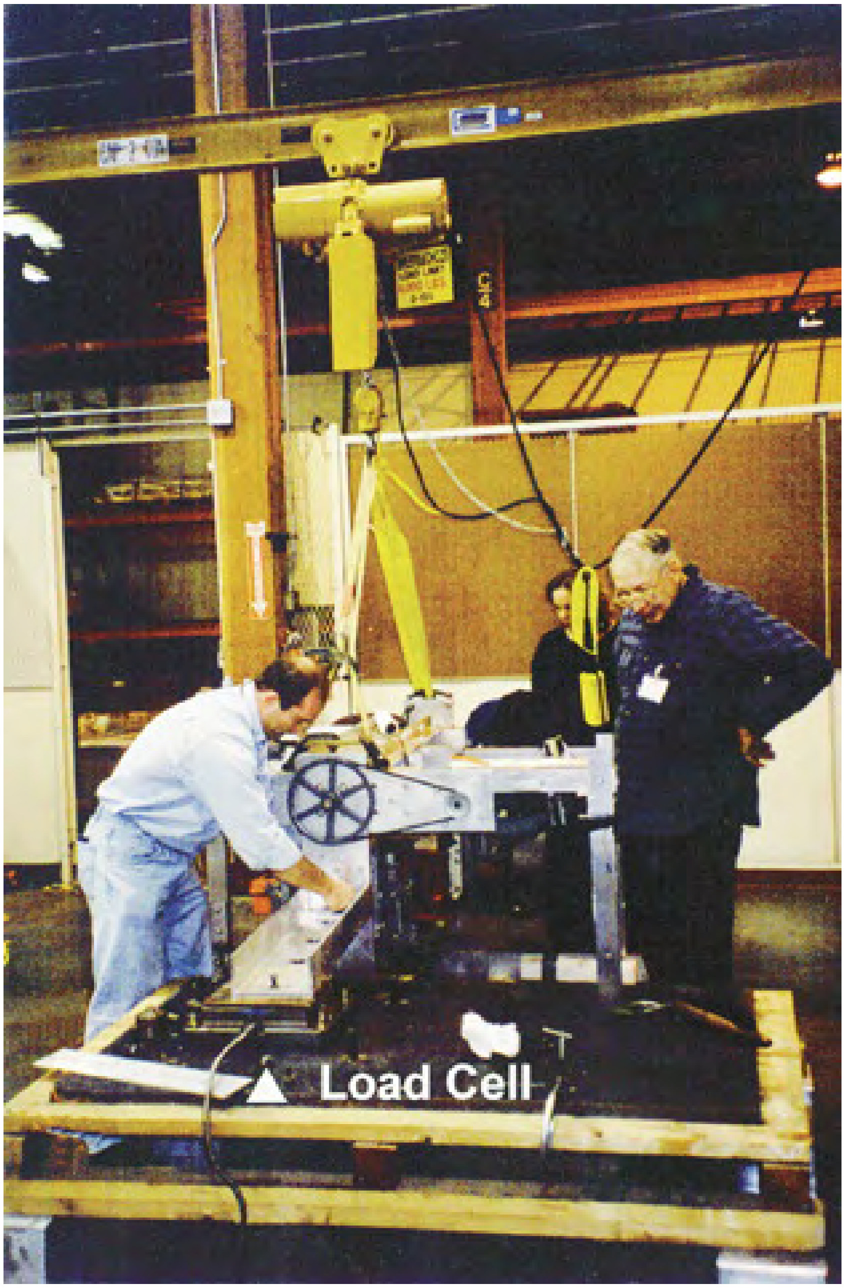
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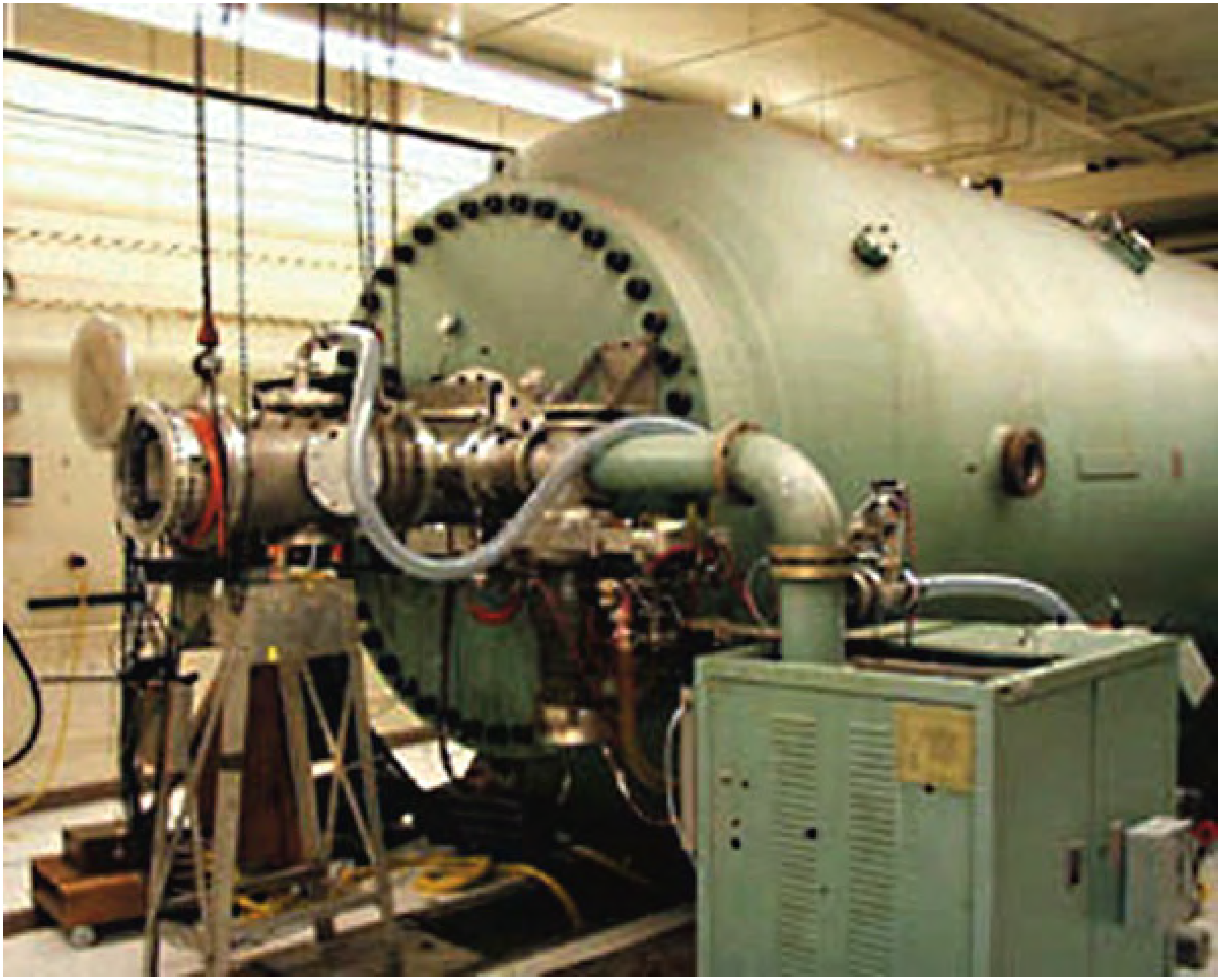


FEATURES

Date Posted: July 24, 2000

JANE'S DEFENCE WEEKLY - JULY 26, 2000

Electrogravitics: the positive approach

One area of research not included in the NASA Breakthrough Propulsion Physics study, but which is touted by some as having the potential to leap the current state of the art in aerospace technology, is 'electrogravitics'.

This is a postulated form of lift based on the controversial assertion that a capacitor charged positively on one side and negatively on the other will experience weight loss, exhibiting thrust in the direction of its positive pole.

In 1952, the man generally described as the 'father of electrogravitics', US inventor Thomas Townsend Brown, submitted a proposal for a 'joint services research and development contract' outlining an electrogravitics aerospace programme called 'Project Winterhaven'. This set out how the US military could go about constructing a Mach 3 manned interceptor utilising electrogravitics technology. Brown based his data on a series of demonstrations he gave to the US Navy immediately after the Second World War.

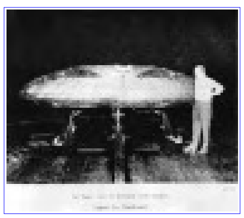
In these and subsequent tests, 2ft (61cm) diameter disc-shaped capacitors charged with 50 kilovolts and a continuous energy input of 50 watts are said to have achieved a speed of 17ft/s in a circular air course 20ft in diameter. A second series of tests, in which slightly larger discs were supposedly charged at 150 kilovolts, were rumoured in the mid-1950s to have exhibited results "so impressive as to be highly classified". This has led to claims by proponents of the technology that the US government has conducted a clandestine electrogravitics effort ever since under the auspices of a 'deep black' test programme.

Lending possible credence to that assertion is this photograph, published here for the first time. It is purportedly of a sub-scale electrogravitics experimental air vehicle mounted on a wind-tunnel test-stand somewhere in the USA. Although *Jane's Defence Weekly* cannot verify its origins, it appears to have been taken in the late 1950s or early 1960s. Intriguingly, Brown recommended the construction of a 10ft diameter disc charged at 500 kilovolts as part of 'Project Winterhaven'.

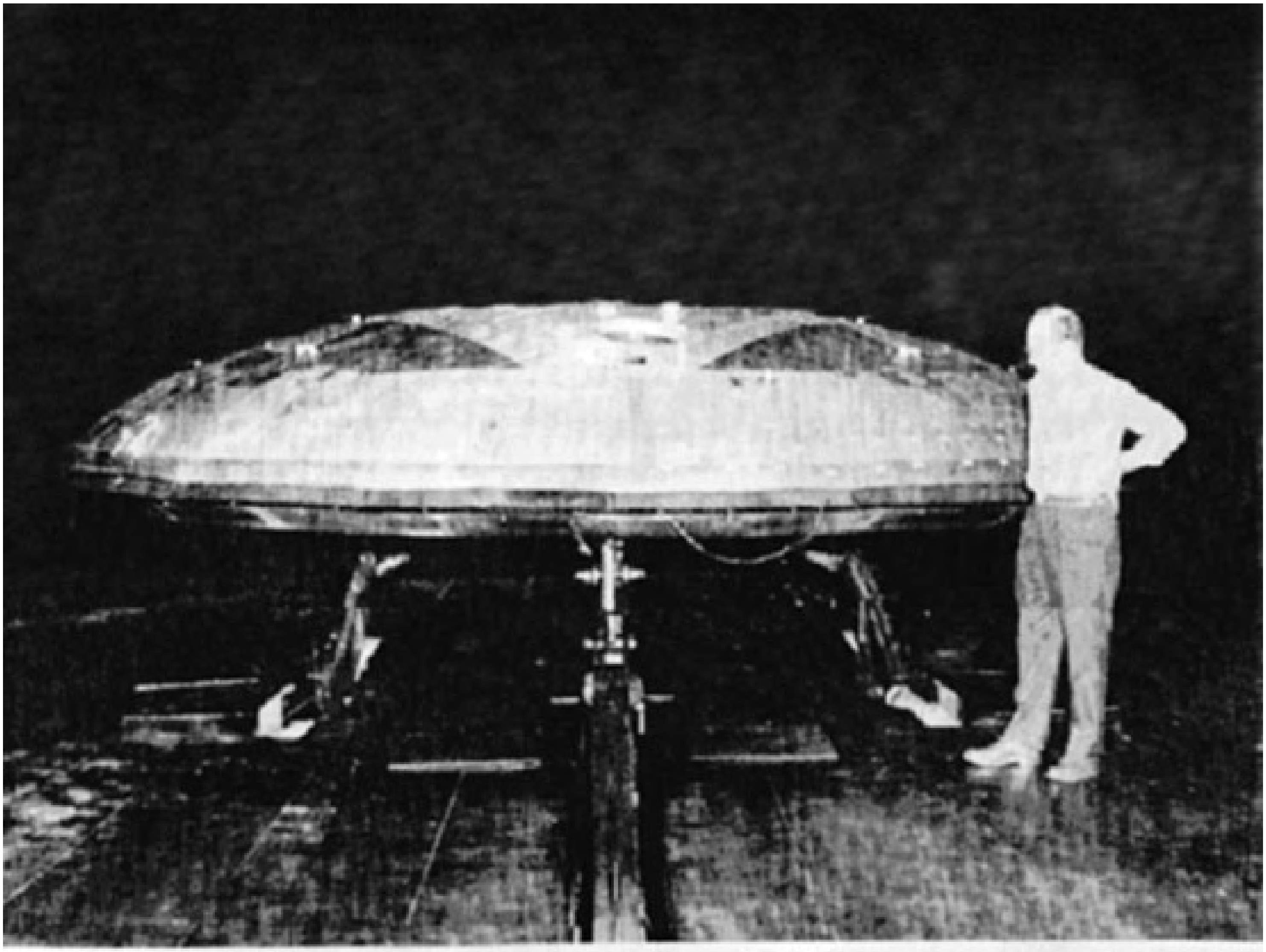
Officially, the US Air Force and Navy lost interest in electrogravitics when their analysis showed that the movement of Brown's capacitors was caused by 'ionic wind' - the displacement of ions around the surface of the charged plates. Brown later claimed to refute this by conducting the tests in a vacuum.

With one or two exceptions, aerospace companies have studiously ignored breakthrough propulsion concepts such as those proposed by Brown and Podkletnov. BAE Systems describes its 'Project Greenglow' initiative as a "speculative research programme" into esoteric propulsion concepts (such as **anti-gravity**) and the Boeing Phantom Works recently conducted tests on a 'reactionless drive' device that apparently contravenes Newton's Third Law of action-reaction. Boeing concluded that the device, which uses two spinning arms transferred through three-dimensions, did work, though not yet at the required impulses for endo-atmospheric propulsion or practical space flight.

Echoing Frank Whittle's early pioneering work on turbojets in the 1920s and 1930s, however, there are those who say it might just be the start of something with far-reaching consequences for the entire future of transportation.



This late 1950s or early 1960s picture is said to be a sub-scale electrogravitics experimental air vehicle mounted on a wind-tunnel test stand
(Source: Jane's)



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(c) Rear view at minimum test height.

Figure 1.- Concluded.

FEATURES

Date Posted: July 24, 2000

JANE'S DEFENCE WEEKLY - JULY 26, 2000

WARP DRIVE: WHEN?

INTRODUCTION:
NASA recently awarded a set of contracts that aim to prove if propulsion concepts behind the warp-drive system of the Starship *Enterprise* may be closer to reality than we think. Nick Cook reports on the breakthrough science that may one day make current aerospace technology as relevant as the Steam Age

Nick Cook *JDW's Aviation Editor*
London

In three years' time it will be exactly a century since the Wright Brothers achieved sustained powered flight at Kitty Hawk, North Carolina. Compared to ships and trains, aviation is still a young mode of transport, but already some people are asking whether it has hit the buffers of scientific limits.

On both sides of the Atlantic, aerospace companies and government research centres spend millions of dollars annually to reduce airframe drag factors by increments of a percentage point or two.

In the propulsion field, an investment of hundreds of millions of dollars is required from one generation of engine to the next to reduce fuel consumption figures by fractions. In spaceflight, the rockets that loft satellites into orbit at a cost of $5,000 per kilogram comprise the same basic technology as the V2 ballistic missiles developed by Germany during the Second World War. To go beyond the Space Shuttle Orbiter, the US government will spend billions more dollars developing a totally reusable launch vehicle, the VentureStar.

Yet, even VentureStar, which - if it ever goes ahead - will represent an enormous leap forward, will fall victim to the same laws of physics as any other rocket. At the moment of launch, fuel will account for almost 90% of its weight, and this simply to deliver a relatively small payload into low earth orbit. Brute force solutions to air and space flight require high energy levels to sustain them; and this - for aircraft as well as rockets - means heavy, expensive and potentially explosive fuel loads.

At the US National Aeronautics and Space Administration (NASA), a tiny research effort costing approximately half a million dollars has been set up to pose, rather than answer, a simple series of questions: does aerospace propulsion have to remain locked into this incremental improvement cycle? Or are there quantum leaps in science that can be tapped into to circumvent the evolutionary process - as was achieved with the development of the jet engine more than half a century ago?

The NASA effort is called the Breakthrough Propulsion Physics (BPP) programme and it is run out of the administration's Glenn Research Center at Cleveland, Ohio.

Although only peripherally seeking endo-atmospheric payoffs, as the big picture is mainly concerned with space travel, BPP does raise fundamental questions about the future of aerospace as a scientific and engineering discipline. That it is doing so now hinges on the fact that NASA officials believe there may be "emerging clues" to new propulsion methods, based on some recent "provocative developments", that could point the way to some startling advances.

BPP is part of the Advanced Space Transportation Plan (ASTP), managed by the NASA Marshall Space Flight Center in Alabama. ASTP is a long-range effort that seeks to develop new low-cost space launch and transfer technologies.

Its remit is also to come up with visionary ideas for future space transport systems - ideas that if ever translated into hardware might make future trips to other star systems possible.

BPP stemmed from some fundamental questions asked by NASA administrator Dan Goldin in 1996 about perceived physical limits to the advancement of aerospace and the exploration of space - areas such as light speed and gravity control. The former was until recently deemed to be unsurpassable, the latter little more than a notional curiosity.

One of the people within the organisation also asking these questions was Marc Millis at NASA Glenn (formerly the NASA Lewis Research Center). Millis and a number of colleagues had been scanning physics literature for years for theoretical ideas; many of them more closely allied to science-fiction than physical reality; that might one day be exploited for deep space travel. The results were posted on a website called 'Warp-Drive: When?'

The website managed to catch the attention of the ASTP team at Marshall, which had staff of its own examining similar kinds of issues. 'Warp-Drive: When?' examines theories ranging from the potential existence of 'worm-holes' - portals connecting distant parts of the universe - and the feasibility of bending space-time, the principle at the heart of the Starship *Enterprise's* warp-drive system in the 'Star Trek' television series.

BPP became official when NASA Marshall asked Millis to propose a formal programme based on what, until then, had largely been a hobby.

"In the NASA charter we're supposed to sustain pre-eminence in the science and technology of air- and space-flight," Millis says. "To do that we have to look at the edge." Determining the location of the 'edge' was not easy.

Millis illustrates the point with a chart that shows technology on a scale spanning 'routine' - that which is in use today - to 'conjecture' - ideas that are based on "visions without knowledge", the stuff of science-fiction.

"We're also supposed to be prudent investors of the tax-payer's money, which means you have to strike a balance," he says. Consequently, BPP, which is categorised as 'emerging science', is positioned on Millis' chart somewhere between 'science' ("nature understood: when you know what is theoretically possible") and 'speculation' ("knowledgeable conjecture: when you know what you know, and know what you don't"). It is so cutting-edge that much of it is based on science that traditionalists would write off as impossible.

BPP's aim is to deliver progress towards achieving breakthroughs, rather than delivering the breakthroughs themselves. In seeking submissions that would challenge thinking in many areas of accepted physics, it has received 13 proposals that Millis and his panel of expert reviewers considered acceptable. But with its $450,000 budget, it could only afford to let five contracts. These were awarded between December 1999 and February this year.

The successful bidders placed considerable importance on experimental observation via what Millis describes as "affordable, short-term, relevant research". They must submit their results within the next 12 months to three years.

The first experiment, by Dr John Cramer of Washington University, Seattle, will test a transient inertia effect supposedly observed a decade ago by a scientist called James Woodward in which it was asserted via experiment and theory that a change in inertia is possible with a sudden energy density change.

Manipulate the inertia of an object like a spacecraft and you have the ability to dramatically reduce, if not negate altogether, its need for propellant. But this implies a fundamentally new way of creating motion and a fundamental shift in our understanding of physics. Cramer's experiment is designed to prove one way or another whether Woodward's original experimentation was sound or flawed. The second experiment by Dr Jordan Maclay and a small industry team from Hunstville, Alabama, will examine the existence of the so-called Zero Point Energy (ZPE) field and whether it exists at the magnitudes that have been postulated. If so, it could be of immense practical value for space travel as well as leading to entirely new sources of non-polluting energy here on earth.

For some years there has been a developing understanding that space is not the empty vacuum of traditional theory, but a seething mass of energy, with particles arising and disappearing and fields continuously fluctuating about their 'zero-point' baselines. These fluctuations of the vacuum remain even at absolute zero or the zero point of temperature - hence the name. If the ZPE field can be 'mined' in space for practical use it would yield an infinite energy source for propulsion.

The third experiment is a test of 'electrodynamic torsion tensor theory'. This will examine the as yet unproven link between electromagnetism and gravity and its impact on space-time. "The immediate utility (for propulsion purposes) is not obvious," Millis says, "but it's like a foot in the door." Perturbations of space-time, however, open up esoteric possibilities such as time travel, as well as the potential for crossing vast oceans of the universe.

The fourth experiment, by Dr Kevin Malloy of the University of New Mexico in Albuquerque, looks at 'superluminal quantum tunnelling': faster-than-light speed. Recent tests have shown light pulses apparently accelerating beyond the speed of light, thereby shattering Einstein's theory of relativity, which says the light speed barrier cannot be breached.

The BPP experiment aims to prove definitively whether the superluminal effect is indeed real. "It's really only touching on the make or break issue of whether you can have a faster than light phenomenon," Millis says. "If the answer is 'yes', how that translates into space travel is way down the pike."

The fifth experiment is no less controversial. Conducted under the auspices of the Marshall Space Flight Center itself, it will set out to prove or disprove a highly contentious claim by Russian scientist Evgeny Podkletnov, that he has negated the forces of gravity using super-conducting ceramic discs rotated above powerful electromagnets. The claims were first made public in 1996 when Podkletnov, a materials scientist, was working at the University of Tampere in Finland.

Since then, NASA Marshall and the University of Alabama at Huntsville (UAH) have been putting his claim to the test. They have found cause to believe that something unusual is occurring, although the precise nature of the effect is a matter of conjecture. In his initial tests, Podkletnov claimed that objects he placed above superconductors spinning at 5,000rpm were losing 2% of their weight and, crucially, that the tests were repeatable.

More recently, at a lecture organised by BAE Systems at the University of Sheffield in the UK in February this year, Podkletnov openly claimed that for a short period of time objects placed in the area of influence above the disc were losing up to 5% of their weight. Higher rotation speeds, Podkletnov told *Jane's Defence Weekly,* had shown that even more dramatic reductions were possible.

Podkletnov, who is now working with the Japanese industry to fine-tune his findings and produce hardware, maintains that the key to success lies in the way in which the superconducting discs are fabricated - a secret he is keeping close to his chest. Part of the problem faced by the NASA/UAH team has been its inability to reproduce superconductors of the size and fidelity Podkletnov says are needed to achieve the desired results.

Under a small business industry research grant outside the BPP programme but running in parallel, a company in Columbus, Ohio, will seek to demonstrate the feasibility of building discs suitable for the BPP gravity shielding experiments - a term with which even Millis is uncomfortable. "It's more accurate to call it an anomalous gravitational effect, but even whether or not it's a gravitational effect is jumping the gun," he says. It could, he adds, simply be an experimental error.

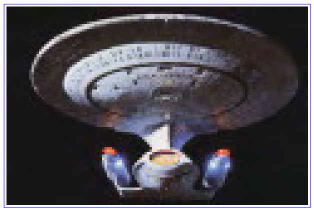
If Podkletnov has discovered a genuine effect, however, its impact on aerospace could be enormous, which is why NASA feels it cannot afford to ignore his work. "If using controllable hardware, you can be creating forces at a distance or manipulating gravity and inertia, it would be a breakthrough and have substantial utility to a NASA mission," Millis says.

Although physicists do not like to use the term '**anti-gravity**', because of its pseudo-scientific connotations, such hardware would usher in an entire new era of propulsion. Podkletnov himself is convinced that his work will be applied to endo-atmospheric aerospace vehicles as well as spacecraft - and sooner, perhaps, than the world of conventional aerospace engineering would like to think.

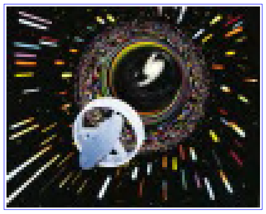
In experiments using rotation speeds far in excess of those used in his early work, Podkletnov said that his superconducting discs had actually taken off.

The US Air Force maintains close links with BPP and is updated at significant milestones. It conducted investigations of its own into breakthrough propulsion physics - one such was the 1990 Electric Propulsion Study commissioned by the Space Systems Division of Air Force Systems Command at Edwards Air Force Base, California. "If the US Air Force or Navy are doing restricted work in this area, it's not a part of this programme," Millis says, as the BPP programme aims to keep work in the public domain and unrestricted.

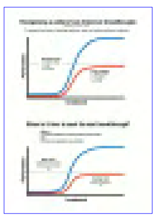
And if NASA does hit upon a real breakthrough? "We have to keep an eye out for how things are advancing," Millis says. "For example, if we were to have a breakthrough where you could immediately engineer a device, then we have to reassess what is the impact of this. By having the air force and other military people as part of the network means we're just poised to do that should it happen."



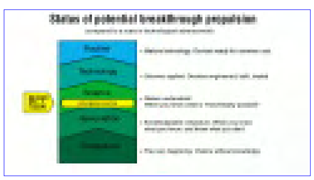
NASA's Breakthrough Propulsion Programme want to determine if a space flight system like the starship Enterprise's warp drive system could be a reality
(Source: Paramount Pictures)



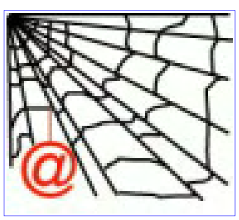
Hypothetical spacecraft with a "negative energy" induction ring, inspired by recent theories describing how space could be warped with negative energy to produce hyperfast transport
(Source: NASA/Les Bossinas)



Recognising a pattern from historical breakthroughs
(Source: Jane's)



Status of potential breakthrough propulsion
(Source: Jane's)



http://www.grc.nasa.gov/WWW/PAO/warp.htm
(Source: Jane's)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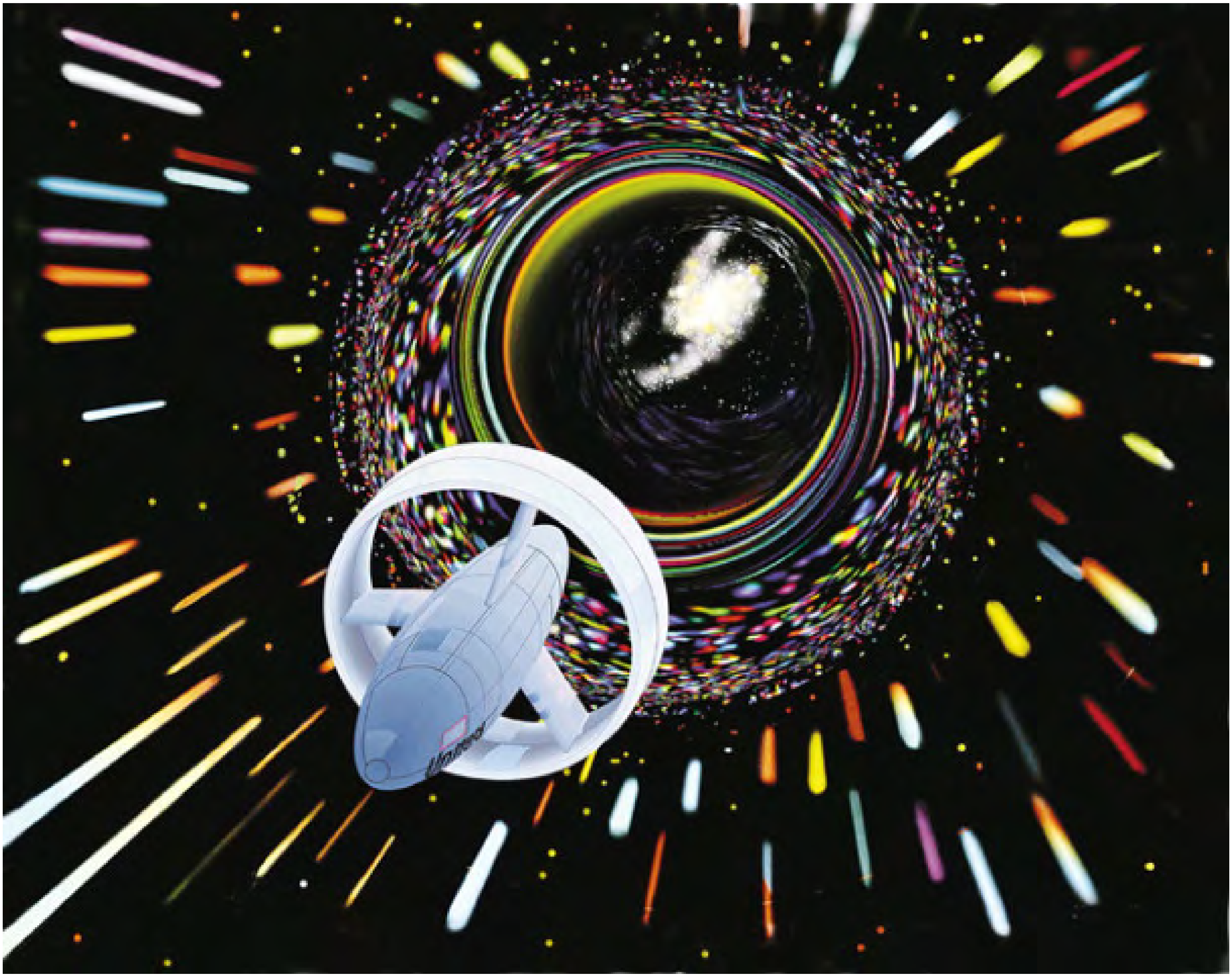
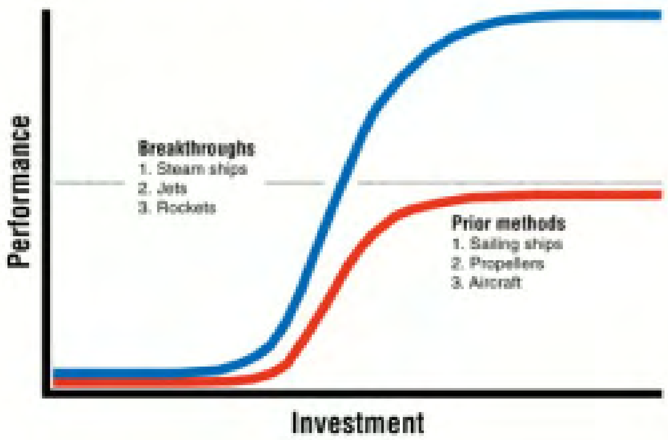


Recognising a pattern from historical breakthroughs

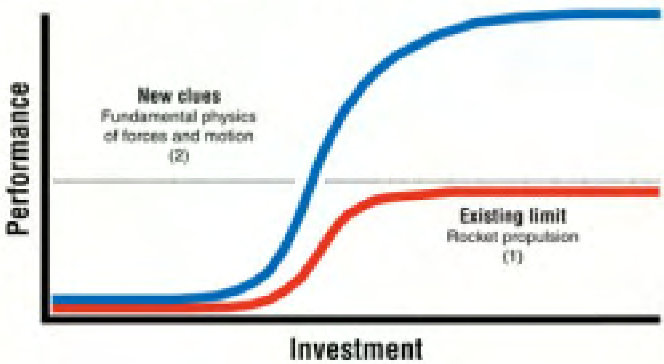
(adapted from Foster, 1986)

To exceed the limits of existing methods, seek out entirely different methods



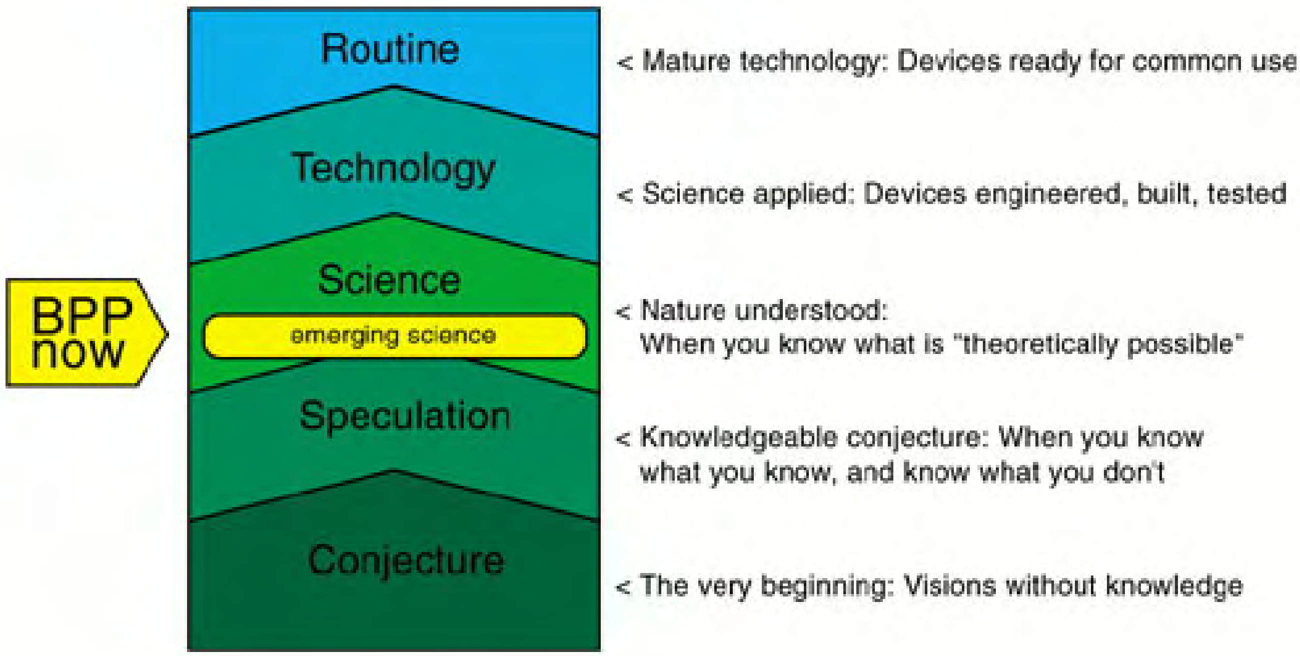
When is it time to seek the next breakthrough?

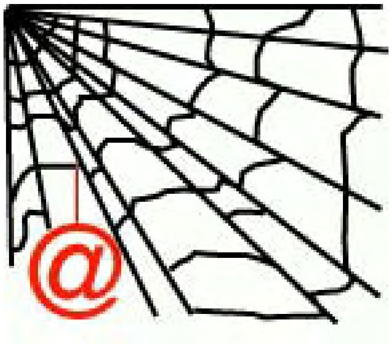
When...
(1) existing methods are reaching their theoretical limits
and
(2) clues are emerging for new methods



Status of potential breakthrough propulsion

(compared to a scale of technological advancement)





VISION 2020, TURNING SCIENCE FICTION INTO FACT p 30

JANE'S DEFENCE WEEKLY

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BY LINE:
Nick Cook

INTRODUCTION:
Not only the US Air Force is investing time and money in future air vehicle technology, as Nick Cook reports

TEXT:
Technologists who dabble in the interpretation of visions do not always get it right. Take this example from a specialist US aviation magazine in 1956: "We're already working with equipment to cancel out gravity," Lawrence D Bell, founder of the company that bears his name, was quoted as saying.

Bell, apparently, was not the only one working in this field. Others said to be seeking to master this arcane `science' included the Glenn L Martin Company, Convair, Lear and Sperry Gyroscope. Within a few years, we were assured, aircraft, cars, submarines and power stations would all be driven by this radical new propulsion technology. Sadly, it was not to be.

However, despite some notable setbacks, the US Air Force has never given up on its `vision'. The word recurs again and again in service literature and is always on the lips of those who run its science and technology (S&T) programmes. In no other air force - in no other nation - is such prominence given to the techno-visionary.

USAF is constantly looking 25 to 30 years ahead. It encourages those who work within the service - and the companies that build systems for it - to gaze into the future, to set ambitious goals and to strive to realize them. It goes so far as to map out this vision in unclassified literature - the periodically released `Air Force S&T Program' - and has a formal mechanism for bringing revolutionary technologies to the boil. The latest example of this, Project Forecast II - the third in a series of studies going back to 1944 - was published in 1985.

Between the S&T Program and Forecast II, we are afforded a glimpse of what might be in 2020. By comparing these documents with the Pentagon's last Defense Technology Plan, published last September, which gazes a maximum of 10 years ahead, it is also possible to zero in on what revolutionary advances USAF may be looking for. The picture is only partly representative because of the enormous resources allocated to `black' projects, programmes so sensitive that, technically, they do not exist. By their very nature, many future projects fall into this category. The picture is also blurred by USAF's failure to publish an `S&T Program' since 1990 and the enormous political and military upheavals that have taken place in the interim.

Yet, revolutionary technology, according to USAF, is only partly dependent on these external forces. As well as what USAF calls `capability needs' - requirements specified by its user commands - the other big driver is `technology innovation': "the process," says the S&T Program, "whereby an air force laboratory or industry team conceives of a new technology and interests users in exploiting its capability." It goes on: "Most of the really significant improvements in military technology - radar, jet engines and the atomic bomb - occur this way." Even so, quantum leaps require a great deal of funding, and the USAF's S&T community, like the rest of the US military, finds itself with a static budget and short on personnel. USAF R&D and S&T funding for FY95, however, still hovers around the $11.5 billion mark - a considerable amount of money. Enough, certainly, to transition some key technologies to the user commands and so maintain technological superiority, considered by USAF to be the `backbone of deterrence', well into the 21st century.

HYPERSONICS

Despite a rash of observer `sightings' of unidentified high speed, high flying air vehicles in the late 1980s and early 1990s, the US Government has consistently denied it has developed or is developing an aircraft to replace the Mach 3-plus Lockheed SR-71 strategic reconnaissance platform. Its blanket denials of an `Aurora-type' capability included hypersonic aircraft for missions other than reconnaissance.

That USAF entertained hypersonic ambitions for a range of roles in the mid-to-late 1980s, however, is not in dispute. Four out of eight `mission area summaries' for air vehicles in the `1990 S&T Plan' - strategic offence, strategic defence, space and recce/intel - called for a NASP-derived vehicle to replace current bombers, orbital launch vehicles and reconnaissance aircraft.

NASP was the X-30
National Aero-Space Plane, a NASA-led effort, since cancelled on funding and technical grounds.

Forecast II said: "The air force will be able to go into space and de-orbit on demand as a result of the improved understanding of hypersonic aerodynamics, particularly in the Mach 8 and Mach 25 regime." With NASP cancelled and, apparently, no Aurora capability in the offing either, does this mean USAF has abandoned all hope of fielding a hypersonic platform in the future? Apparently not.

In last year's Defense Technology Plan, a `roadmap of technology objectives' lists a "flight demonstration of (a) Mach 8 hydrocarbon-fuelled scramjet (supersonic combustion ramjet)" as one of its key goals by 2005 in the aerospace propulsion field. Elsewhere, the document says, "the demonstration of a scramjet to M>12 may lay the foundation for single-stage to orbit space launch." That such a capability is not undergoing significant development in the classified R&D arena would, many qualified observers believe, be highly unusual. Mastering hypersonics is certainly consistent with one of two current overriding drives within USAF labs - operating at ever increasing range from the Continental USA (the other is making current technologies more affordable) as US overseas forces contract.

GAS TURBINE INCREMENTS

Research into more conventional aero-engine propulsion continues via the Integrated High-Performance Turbine Engine Technology (IHPTET) programme and other comparable efforts outside the USA. By 2005, the IHPTET will be delivering 100 per cent thrust-to-weight improvements over current fighter-type jet engines.

In the UK, Rolls-Royce is locked into a technology demonstration schedule that, all things being equal, will see it running a combat engine in the same time period with a 60 per cent improvement in thrust-to-weight ratio over the Eurofighter 2000's EJ 200 - an airframe-powerplant combination that, as Jane's Defence Weekly went to press, is yet to fly. Though less dramatic improvements will always be sought in other aspects of engine development - fuel burn, life-cycle and acquisition cost, for example - radical enhancements of the jet engine itself are finite. Doubling the power-to-weight ratio again by 2020 may simply not be worth the effort or cost. Alternatively, pushing for all-out power may have an adverse effect in other areas, such as `signature management', ensuring engines remain as stealthy as their airframes.

THE SUPER COCKPIT

"Machines," according to Forecast II, "must respond reliably to voice commands and eye motion signals, and man and machine must interact to share the sense of touch." An area of research that will be critical in achieving this is virtual reality. It is predicted that the virtual cockpit - the pilot deriving his or her entire view of the outside world via cockpit and helmet displays - will begin equipping operational aircraft in 2020. Research at Aeronautical Systems Center laboratories at Wright-Patterson Air Force Base, Ohio, embodies the essence of what USAF calls the Super Cockpit. According to Forecast II, a two-way flow of visual and aural information between pilot and aircraft will enable him or her to aim and fire weapons or to activate other cockpit functions simply by looking or talking. Add `thinking' to that list and the picture is even more complete.

Revolutionary advances in the cockpit will be helped by a shift towards commercial off-the-shelf avionics, especially in the computer processor arena.

Modular avionics, based on slide-in, slide-out processor cards, will allow users to improve sensors and cockpit systems without implementing costly mid-life upgrades. Situational awareness will also be vastly improved thanks to real-time access to satellite communications, imagery and other intelligence information distributed between every echelon of the command and fighting forces. Also growing in importance are mission planning and rehearsal tools - most of them PC based - that allow pilots to fly sorties `virtually' before they have even taken off to strike the target.

WEAPONS

In the `conventional armament' field, USAF's goal is to develop `affordable, autonomous, all-weather, day and night stand-off weapon technologies that provide near-perfect accuracy'. By 2020, it will probably be dependent on an advanced ramjet-powered version of, or successor to, the AMRAAM medium-range air-to-air missile and the short-range AIM-9X dogfight missile or its pre-planned product improvement. Available P3I options are likely to include multi-spectral, stealth-defeating seekers. Beyond improvements to the next-generation air-to-surface weaponry typified by the Joint Direct-Attack Munition and the Joint StandOff Weapon, other more exotic technologies are being sought for soft and hard kill options. "We will transition high and medium power microwave technologies to developers for use as weapons, broadband countermeasure devices, radars and enhanced jammers," the S&T Program reports. "We anticipate breakthroughs in long-range, high-altitude, very high-velocity impact weaponry for use against a variety of hardened (including very deep) targets," Forecast II adds. This has been given added impetus by the development of Third World weapons of mass destruction, which might typically be stored in such places. The current development of an airborne laser for boost phase interception of theatre ballistic missiles is one of those rare leaps in capability that will change the way wars are fought. By 2020, miniaturization techniques may result in deploying lasers in smaller, tactical aircraft. Increased application of photonic as opposed to electronic-based equipment will make user aircraft less susceptible to damage from the EW threat. `Smart skins' - outer panels containing embedded sensors - will allow aircraft to sense and communicate across multiple frequency bands in any direction from any attitude.

STEALTH

In 1985 and 1990, Stealth was so sensitive that Forecast II and the S&T Program barely gave it a mention. Stealth has changed irrevocably the way in which war in the air is being and will be fought. The USA - and other Western technical powers like France, the UK and Germany - are pouring considerable funds into the mastery of both Stealth and Counter-Stealth technologies.

Take the UK, for example. Since the mid-late 1980s, British Aerospace Warton has pumped over Pds100 million ($160 million) - about half of it coming from government sources - into infrastructure improvements geared towards Stealth. Much of this activity is aimed at meeting the RAF's need for a Future Offensive Aircraft (FOA) to replace the Tornado IDS. Traditionally, US firms such as Lockheed and Northrop have enjoyed a US-only monopoly in black programming - the development of aircraft that are invisible to public scrutiny.

Recent revelations that BAe is establishing a `Skunk Works' on its own remote site at Warton and that the Germans tested manned wind-tunnel models of their Stealth fighter, the Lampyridae, in the mid-1980s - when the first-generation Lockheed F-117 was still so classified its existence was officially denied - show an emerging trend towards `black' programme secrecy in Europe, mirroring that of the USA.

Together with advanced, lean manufacturing techniques that will allow companies to rapid-prototype and build small batches of aircraft at low cost, expect more from these countries in the way of classified technology demonstration and even low-volume production programmes, including full-sized air vehicles. `More', because according to numerous sources, such activity is well advanced already. In the USA, it is widely accepted that a third generation of true Stealth aircraft (beyond the first generation F-117 and the second generation B-2) is already under test and perhaps even in service for missions spanning strike and defence suppression as well as tactical and strategic reconnaissance.

BEYOND 2001

Groom Lake, Nevada, is the epicentre of classified USAF research into Stealth and other exotic aerospace technologies. Several years after the collapse of the Soviet threat, activity and investment at this remote, highly secret air base (so secret its presence is, as yet, unacknowledged by the US Government) is still on the increase. While research into less sensitive technologies such as two-dimensional thrust-vectoring and advanced short take-off and vertical landing (ASTOVL) are pursued in the open at nearby Edwards AFB in California, Groom Lake is set to hang onto its secrets. The USAF's recent confiscation of 1600 ha of public land bordering the facility is consistent with the Pentagon's desire to maintain its lead in quantum leap technologies - some of which, according to well qualified observers in and around the Nevada area, defy current thinking into the predicted direction of aerospace engineering.

That aerospace companies continue to look at highly radical alternative air vehicle concepts is evidence of the ongoing quest for breakthrough designs. Glimpses into this world are rare, but provide some insight into likely 21st century research activity. The 1990 unclassified `Electric Propulsion Study' (a quest for an antigravity propulsion system by another name) conducted by the USA's Science Applications International Corp on behalf of USAF's then-Astronautics Laboratory at Edwards AFB, shows that USAF's visionaries are still being given free rein. Until recently, BAe also provided internal resources for its own **anti-gravity** studies and even went so far as to outline this thinking with artists' concepts - a case of Lawrence Bell's vision perhaps being not so wide of the mark after all.

Before he died, Ben Rich, who headed Lockheed's Skunk Works from 1975-1991, was quoted as saying: "We have some new things. We are not stagnating. What we are doing is updating ourselves, without advertising. There are some new programmes, and there are certain things - some of them 20 or 30 years old - that are still breakthroughs and appropriate to keep quiet about. Other people don't have them yet."

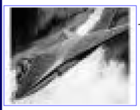
Thirty years from now, we may still not know the half of what is currently being tested in and around Groom Lake.

A manned wind-tunnel model of Germany's medium-range missile fighter, Lampyridae

Lampyridae missile fighter

Lampyridae missile fighter

CAPTION:
A manned wind-tunnel model of Germany's medium-range missile fighter, Lampyridae

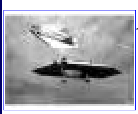


Future Offensive Aircraft

CAPTION:
Artist's concept of British Aerospace's Future Offensive Aircraft for the UK

*Air vehicle using **anti**-**gravity***

CAPTION:
BAe Military Aircraft Division's concept for an air vehicle employing **anti**-**gravity** propulsion

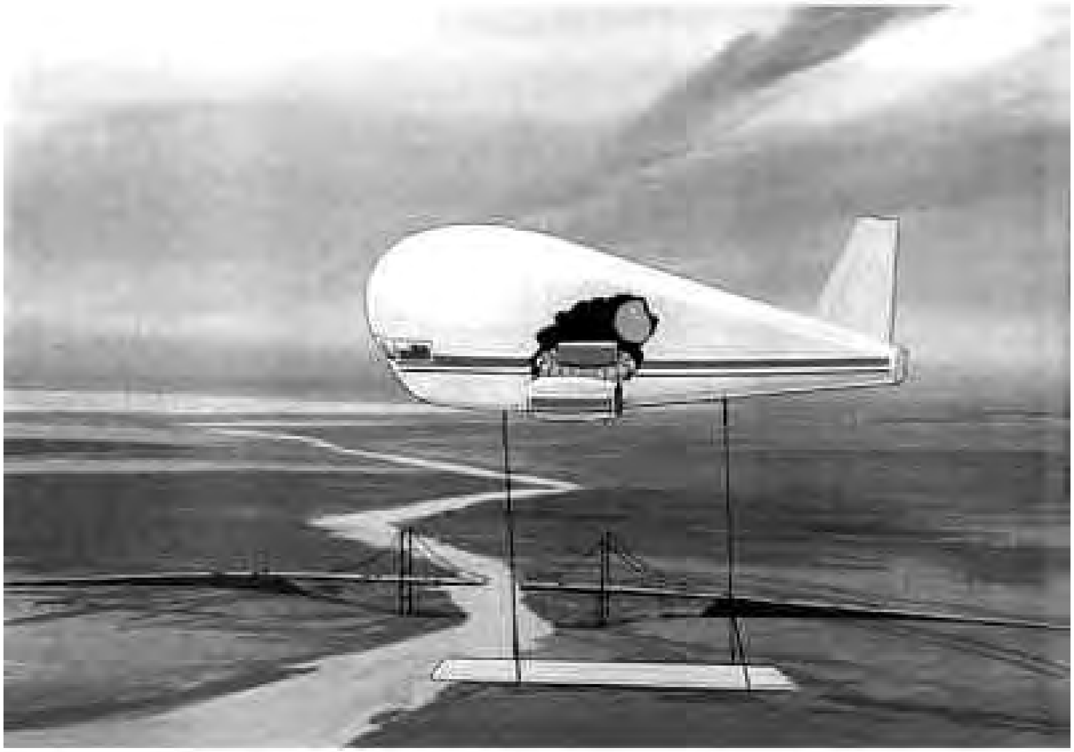


*Air vehicle using **anti**-**gravity***

CAPTION:
Another BAe concept showing an **anti**-**gravity** propulsion system in action

Heavy lift vehicle concept

CAPTION:
BAe concept for a heavy lift vehicle, also using an **anti**-**gravity** propulsion system



THE JANE'S INTERVIEW SCIENCE FICTION AUTHOR ARTHUR C CLARKE **p 32**

JANE'S DEFENCE WEEKLY

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BY LINE:

Nick Cook
Sri Lanka

TEXT:

World famous author Arthur C Clarke has recently found himself in demand by the military to talk on how science fiction is becoming science fact.

These days, Arthur C Clarke, the author of 2001: A Space Odyssey, rarely ventures beyond his home in Colombo, Sri Lanka. He admits he is ``fed up'' with talking to the media. ``However,'' he adds, ``I'm always ready to comment on any major development in my areas of interest - for example, an ET landing on the White House lawn, or the first genuine message from space.''

One recent exception to this self-imposed rule was a talk that he gave to the Pacific Area Senior Officer Logistics Seminar (PASOLS) in Colombo, a gathering of high ranking military officers from countries across the Pacific Rim, including the USA.

Diplomatic observers on the ground were surprised by Clarke's appearance at PASOLS. At the time, it seemed to gel neither with his own leanings - he confesses to being something of a pacifist - nor with the overall theme, a forum for improving the provision of logistics among allies in the region.

The substance of Clarke's address was a short dissertation on the process known as `cold fusion'. Almost five years after two US scientists, Pons and Fleischmann, claimed they had hit upon the reaction that fuels the sun under laboratory, or room temperature conditions - hence the misleading description, `cold fusion' - it is a subject that consumes him greatly.

It is also a highly controversial one. Soon after the two reported their discovery, that more energy was coming out of their experiments than was being put in - the all-important breakthrough - many other laboratories tried to repeat their tests and failed. Pons and Fleischmann were ``laughed out of court'' in Clarke's words, for a number of years. Lately, however, there has been a resurgence of interest in their work, ``an underground movement of scientists,'' according to Clarke, ``who believed there might be something in all this business.'' Fresh experiments, many of them backed by the Japanese, others by the US military, confirmed positive results.

``It is now beyond serious dispute that anomalous amounts of energy are being produced from hydrogen by some unknown reaction,'' Clarke says. However, the theoretical basis of cold fusion is still a mystery, he adds. Though it could be a laboratory curiosity, ``frankly, I doubt this. Anything so novel indicates a breakthrough of some kind.''

For a man who told JDW that he ``won't get contaminated by security'', adding, ``I've never been involved in anything I'm not supposed to talk about,'' Clarke has been doing a fair amount of talking to the military lately. He recently addressed the US Air Force's Air War College at Maxwell Air Force Base, Alabama, via video-phone link on the future of technology in general.

The USAF, unlike most other air forces, is not afraid to solicit the views of science-fiction writers once in a while in an effort to predict the future direction of air warfare. A few years ago, the USAF instituted Project Forecast II, an initiative aimed to produce a handful of `quantum leap' technologies for the 21st century. In 1990, the air force's then Astronautics Laboratory (now Phillips Propulsion Labs) published a report under the Electric Propulsion Study that examined theories and experimental approaches for an `**anti-gravity**' propulsion system. The chances are, therefore, that when he talks to the US military, Clarke's views, including those on on cold fusion, have not fallen on deaf ears.

In 2010: Odyssey II, published in 1982, Clarke pretended that the Russians had invented a spaceship engine based on cold fusion principles worked on by Andrei Sakharov during his exile in Gorky. ``He didn't, of course, so that's a piece of fictitious history. However, three Russian scientists who have indeed been working on nuclear propulsion for rockets have now got into the cold fusion act, and they have just published some startling results.

``They are obtaining about five times their energy input in gas mixtures, not solids, and at temperatures of up to 1800 deg C. Now this is not exactly `cold' fusion - but it's certainly ice-cold compared with the tens of millions of degrees the hot fusioneers are talking about.'' If a plasma fusion rocket could be developed, it would open up the solar system, ``just as the aeroplane opened up this planet,'' he says.

Back on earth, cold fusion would essentially mean the end of the Fossil Fuel Age, Clarke says; an era of cheap, clean power. ``The environmental benefits would be overwhelming.'' Eschewing the ways of the military as he does, perhaps this is the real message Arthur C Clarke wants the military men to take away with them.

CAPTION:

Photograph:

COLLABORATE OR PROTECT? **p 56**

JANE'S DEFENCE WEEKLY

DATE: JUNE 12, 1993
EDITION: 1993
VOLUME/ISSUE: 019/024

TEXT:

In an atmosphere of increasing tension over its trade links with Europe and

Japan, the USA is having to define how much of this impressive science and technology base it protects (see box 2) and how much it shares with its traditional allies in future joint collaborative efforts.

Since the evaporation of the Soviet threat, defence R&D between the USA and its NATO allies has drifted through lack of focus and funding. The Pentagon has promised Congress renewed emphasis on the programme, including more speedy negotiations and implementation of bilateral agreements, but its commitment to many of these initiatives is unclear.

Twenty-six areas of potential co-operative research between USAF's Electronic Systems Center (ESC) and Japan were identified by some 70 programme managers and engineers in an ESC/Japan initiative conference in February. The Japan initiative was designed to target Japan's defence industry and technology market for possible international co-operative R&D efforts with ESC.

Potential areas of co-operation include: the miniaturization of radar technology, fibre optics, tactical communications, sensors, lasers, smart skin radars, computer language translation, robotics, advanced wafer technology, theatre missile defence, improved over-the-horizon radar, modelling and simulation, use of sonar and acoustics technology to test materials and Japanese AWACS technology. Various USAF offices will now pursue co-operative efforts in these areas.

Within Europe, the UK is the chief beneficiary of shared S&T research with the United States. Through the Master Information Exchange Agreement (MIEA) -- the technology transfer provision of the US/UK 'special relationship' -- the UK's government research establishments enjoy a two-way exchange of technical data that is the envy of other US allies.

The depth of the relationship is illustrated by the fact that, according to reliable UK sources, the UK's Royal Aeronautical Establishment (now the Defence Research Agency) was passed technical data on the Lockheed F-117 Stealth Fighter in the mid-1980s, long before it ceased to be a heavily compartmentalized programme in the USA.

According to UK officials, the USA only conducts extensive (and often highly sensitive) co-operative research with an ally when that nation comes along with a technological advantage in a given area, or areas. It is significant, for example, that USAF's ESC initiative with Japan focuses on many of the five technologies (mentioned at the beginning of this article) in which Japan was deemed to be "significantly ahead" of the USA by USAF.

Of course, when the USA, or any other country, feels it has an overwhelming advantage in a particular field of military science, it classifies it.

The idea of 'facetting' an aircraft to make it stealthy (the approach adopted for the F-117), only transitioned from the white, to the black world -- in the form of the DARPA Have Blue technology demonstrator programme -- when DoD officials believed what US scientists had been saying openly for some years: that near absolute radar invisibility was achievable.

In the same way, if any Project Forecast II-type technologies were to result in breakthrough -- a quantum leap such as the key to the secret of gravity, say -- the USAF would undoubtedly move to bury it beneath so many layers of classification that it would not see the light of day for years.

As a post-script, anyone who believes the 'science' of **anti-gravity** to be too arcane, too esoteric, even for the US Air Force should consider the Electric Propulsion Study undertaken by SAIC for the Astronautics Laboratory, now part of Phillips Lab, in he late 1980s.

The study's primary objective was to "outline physical methods to test theories of inductive coupling between electromagnetic and gravitational forces to determine the feasibility of such methods as they apply to space propulsion" -- in simplified terms, an **anti**-**gravity** propulsion system.

It remains, for some, the ultimate quantum leap.

CAPTION:

Drawing: AFMC: guardian of USAF's wealth in science and technology

CAPTION:

Photograph: The X-30 -- outgrowing of a secret USAF reconnaissance aircraft or pioneering hypervelocity demonstrator?

CAPTION:

Drawing: Myth or reality? Aurora has come to embody secret 'black' aircraft projects (Julian Cook)

CAPTION:

Drawing: The 'More Electric' Aircraft Programme will minimize on-board hydraulics

CAPTION:

Photograph: Sandia National Laboratories, Kirtland AFB: a key component of the New Mexico 'superlab'

CAPTION:

Photograph: Cuts in US nuclear weapons spending is threatening the competitiveness of laboratories like Los Alamos

CAPTION:

Drawing: SAIC proposal for a rail gun satellite launch system reflects US lead in hypervelocity weapons

CAPTION:

Drawing: Los Alamos free electron laser, packaged in a 747, would knock out ballistic missiles soon after launch (Julian Cook)

FEATURES

Date Posted: July 24, 2000

JANE'S DEFENCE WEEKLY - JULY 26, 2000

Electrogravitics: the positive approach

One area of research not included in the NASA Breakthrough Propulsion Physics study, but which is touted by some as having the potential to leap the current state of the art in aerospace technology, is '**electrogravitics**'.

This is a postulated form of lift based on the controversial assertion that a capacitor charged positively on one side and negatively on the other will experience weight loss, exhibiting thrust in the direction of its positive pole.

In 1952, the man generally described as the 'father of **electrogravitics**', US inventor Thomas Townsend Brown, submitted a proposal for a 'joint services research and development contract' outlining an **electrogravitics** aerospace programme called 'Project Winterhaven'. This set out how the US military could go about constructing a Mach 3 manned interceptor utilising **electrogravitics** technology. Brown based his data on a series of demonstrations he gave to the US Navy immediately after the Second World War.

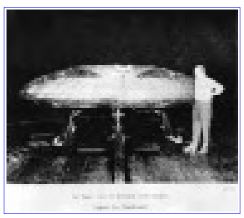
In these and subsequent tests, 2ft (61cm) diameter disc-shaped capacitors charged with 50 kilovolts and a continuous energy input of 50 watts are said to have achieved a speed of 17ft/s in a circular air course 20ft in diameter. A second series of tests, in which slightly larger discs were supposedly charged at 150 kilovolts, were rumoured in the mid-1950s to have exhibited results "so impressive as to be highly classified". This has led to claims by proponents of the technology that the US government has conducted a clandestine **electrogravitics** effort ever since under the auspices of a 'deep black' test programme.

Lending possible credence to that assertion is this photograph, published here for the first time. It is purportedly of a sub-scale **electrogravitics** experimental air vehicle mounted on a wind-tunnel test-stand somewhere in the USA. Although *Jane's Defence Weekly* cannot verify its origins, it appears to have been taken in the late 1950s or early 1960s. Intriguingly, Brown recommended the construction of a 10ft diameter disc charged at 500 kilovolts as part of 'Project Winterhaven'.

Officially, the US Air Force and Navy lost interest in **electrogravitics** when their analysis showed that the movement of Brown's capacitors was caused by 'ionic wind' - the displacement of ions around the surface of the charged plates. Brown later claimed to refute this by conducting the tests in a vacuum.

With one or two exceptions, aerospace companies have studiously ignored breakthrough propulsion concepts such as those proposed by Brown and Podkletnov. BAE Systems describes its 'Project Greenglow' initiative as a "speculative research programme" into esoteric propulsion concepts (such as anti-gravity) and the Boeing Phantom Works recently conducted tests on a 'reactionless drive' device that apparently contravenes Newton's Third Law of action-reaction. Boeing concluded that the device, which uses two spinning arms transferred through three-dimensions, did work, though not yet at the required impulses for endo-atmospheric propulsion or practical space flight.

Echoing Frank Whittle's early pioneering work on turbojets in the 1920s and 1930s, however, there are those who say it might just be the start of something with far-reaching consequences for the entire future of transportation.



This late 1950s or early 1960s picture is said to be a sub-scale ***electrogravitics*** *experimental air vehicle mounted on a wind-tunnel test stand*
(Source: Jane's)

Weighty Implications: NASA Funds Controversial Gravity Shield

By Jack Lucentini
Special to *SPACE.com*
posted: 11:00 am ET
28 September 2000

Brushing aside controversy and a few glitches, NASA officials are forging ahead with plans to build a device that they say could work as an antigravity machine.

Most scientists say the idea of such a gadget is ludicrous. But given the stakes, NASA officials say, it's worth a try.

French astronaut Philippe Perrin floating in France's "Vomit Comet" -- the Airbus 300. These training planes are still the only way to change what you weigh -- short of a trip to space.

A machine that even slightly reduces gravity at spacecraft launch sites, agency officials believe, could save significant amounts of money.

"The fact that it had appeared in a credible scientific journal is what really caught our eye."

The opportunity to try out such a machine is expected to come this May, when an Ohio company is scheduled to finish a prototype of the device for NASA.

Not that the space agency's officials themselves have high hopes.

"To say this is highly speculative is probably putting it mildly," acknowledged Ron Koczor, assistant director for science and technology at the Space Science Laboratory in NASA's Marshall Space Flight Center, Huntsville, Alabama.

Nonetheless, NASA awarded a $600,000 contract last year to Superconductive Components Inc. in Columbus, Ohio to build the device.

Critics say the notion of a "gravity shield" violates Einstein's

The Effects of Gravity

Videos of how gravity governs the universe:

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fundamental laws of physics.

"The theory of gravity is fairly well established, and I don't see it reversing itself," said Francis Slakey, a professor of physics at Georgetown University. The NASA project is "wasted money that could have been used to do legitimate space science," he added.

Koczor portrayed that view as closed-minded.

Scientists such as Slakey "don't seem to be amenable to observing that maybe the laws [of physics] are incomplete," Koczor said.

Throughout history, new discoveries have rocked old assumptions, he pointed out. "People used to talk about laws of conservation of mass, conservation of energy. Then all of a sudden, Einstein comes along and says those are really parts of the same thing."

- Fate of The Milky Way and Andromeda Galaxies
- Mars' Surface Gravity
- Gravitational Microlensing: How massive stars can distort light

Einstein wrote that gravity can be considered a bending of space-time that inevitably occurs around massive objects such as planets and stars. That, the conventional view holds, means no mere machine or invention can make it go away; it is not a "force" that can be counteracted.

The conventional scientists aren't the only critics of the NASA project. The agency is also drawing fire from some of its former collaborators in the effort. To see why, it helps to start from the beginning.

In 1992, a Finnish scientist, Eugene Podkletnov, claimed to have built a device that produced a gravity-shielding effect.

It consisted of a hot, fast-spinning, 12-inch (30-centimeter) disk of a superconducting ceramic, levitating within a magnetic field. Objects above the disk, Podkletnov reported, showed a loss of weight of between about 0.5 percent and 2 percent.

In 1996, researchers at Marshall Space Flight Center decided to investigate the claims. "The fact that it had appeared in a credible scientific journal is what really caught our eye," Koczor said.

Actually, Podkletnov had withdrawn his most recent article from publication under unclear circumstances. But he and others had published research on antigravity phenomena in several peer-reviewed journals.

Koczor assembled a team that worked together with scientists at the nearby University of Alabama at Huntsville, to build a device partially simulating the one Podkletnov had used. But the researchers were unable to replicate Podkletnov's results, and the partnership fell apart last year with bad blood between the two sides.

The university's Larry Smalley, a physics professor, says NASA simply failed to assemble a competent team of scientists who could give the project a serious chance.

The events "amused me, stunned me and upset me," said Smalley, who said he was involved as an observer of the project at the time. "It made me feel like they wasted time, a lot of money and a really golden opportunity to do something."

Smalley said he remains skeptical that Koczor and NASA have the know-how to do anything meaningful with the project.

The main university professor involved with the project, Ning Li, has since left the school. She said she has founded a company in Huntsville that also will market a gravity-shield device.

Li said she dropped the NASA collaboration and decided to work independently after the agency "wasted" the project's money and resources.

Koczor said the project fell apart not because of incompetence, but because Li was primarily interested in proving her theories of why the "gravity shield" would work. That differed from NASA's goal of simply building a working device, he said.

"She wanted the research to focus on her particular theory. Our intent was simply to show there was a gravity effect, without saying 'theory A is right' or 'theory B is right,'" he explained.

Last year, NASA decided to try again, this time by contracting out the construction of the device. Superconductive Components is in communication with Podkletnov as they attempt to build it, Koczor said.

The project is on or ahead of schedule, said J.R. Gaines, vice president of Superconductive Components.

"The superconductor is built. The rest has been designed and fabrication is proceeding," Gaines said. However, he said, he can't offer an opinion on whether the device will actually work. The company's job is simply to build it to the assigned specifications.

"We don't necessarily have a technical opinion," he said, though "we would certainly love to see this work."

Dark Energy: Astronomers Still 'Clueless' About Mystery Force Pushing Galaxies Apart

SCIENCE TUESDAY

By Andrew Chaikin
Editor, Space & Science
posted: 07:00 am ET
15 January 2002

It sounds like something out of a *Star Trek* episode: Dark energy, a mysterious force that no one understands, is causing the universe to fly apart faster and faster. Only a few years ago, if you'd suggested something like that to astronomers, they would have told you to spend less time in front of the TV and more time in the "real" world.

But dark energy is real — or at least, a growing number of astronomers think it is. No one, however, can truly explain it.

"Frankly, we just don't understand it," says Craig Hogan, an astronomer at the University of Washington at Seattle. "We know what its effects are," Hogan says, but as to the details of dark energy, "We're completely clueless about that. And everybody's clueless about it."

Dark energy entered the astronomical scene in 1998, after two groups of astronomers made a survey of exploding stars, or supernovas, in a number of distant galaxies. These researchers found that the supernovas were dimmer than they should have been, and that meant they were farther away than they should have been. The only way for that to happen, the astronomers realized, was if the expansion of the universe had sped up at some time in the past.

Until then, astronomers had generally believed that the cosmic expansion was gradually slowing down, due to the gravitational tugs that individual galaxies exert on one another. But the supernova results implied that some mysterious force was acting against the pull of gravity, causing galaxies to fly away from each other at ever greater speeds.

It was a stunning realization.

At first, other researchers questioned the result; perhaps the supernovas were dimmer because their light was being blocked by clouds of interstellar dust. Or maybe the supernovas themselves were intrinsically dimmer than scientists thought. But with careful checking, and more data, those explanations have largely been put aside, and the dark energy hypothesis has held up.

In one sense, the idea is not completely new. Einstein had included such an "anti-gravity" effect in his theory of general relativity, in his so-called cosmological constant. But Einstein himself, and later many other astronomers, came to regard this as a kind of mathematical contrivance

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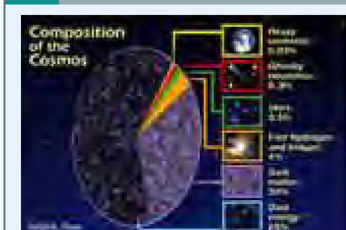

CLICK TO VIEW

This chart shows how much of the universe is made up of dark energy, dark matter, and ordinary matter.

CLICK TO VIEW

This diagram reveals changes in the rate of expansion since the universe's birth 15 billion years ago. The more shallow the curve, the faster the rate of expansion. The curve changes noticeably about 7.5 billion years ago, when objects in the universe beg

Related SPACE.com STORIES

that had little relationship to the real universe. By the 1990s no one expected that the effect would turn out to be real.

Still, anti-gravity isn't the right way to describe dark energy, says Virginia Trimble of the University of Southern California at Irvine.

"It doesn't act opposite to gravity," Trimble says. "It does exactly what general relativity says it should do, if it has negative pressure."

Trimble has a fairly simple way of imagining the phenomenon.

"If you think in terms of the universe as a very large balloon," she says, "when the balloon expands, that makes the local density of the [dark energy] smaller, and so the balloon expands some more …. because it exerts negative pressure. While it's inside the balloon it's trying to pull the balloon back together again, and the lower the density of it there is, the less it can pull back, and the more it expands. This is what happens in the expanding universe."

- Astrophysics Challenged By Dark Energy Finding
- Farthest Supernova Detected, 'Dark Energy' Suspected
- 'Groundbreaking' Discovery: First Direct Observation of Dark Matter
- Understanding Dark Matter and Light Energy

TODAY'S DISCUSSION

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The supernova evidence suggests that the acceleration kicked in about 5 billion years ago. At that time, galaxies were far enough apart that their gravity (which weakens with distance) was overwhelmed by the relatively gentle but constant repulsive force of dark energy. Since then, dark energy's continuing push has been causing the cosmic expansion to speed up, and it seems likely now that this expansion will continue indefinitely.

"It means that if you look out at the universe today, and if we wait many billions of years," says Hogan, "everything will be flying away faster and faster, and eventually we'll be left quite alone."

Aside from such grim forecasts, dark energy is causing quite a bit of upset for astronomers who have to adjust to an unexpected and outlandish new view of the universe. Already, they have had to accept the notion of dark matter, which is now thought to far outnumber ordinary matter in the universe, but which has never been detected in any laboratory. Now, the arrival of an unknown force that rules cosmic expansion has added insult to injury.

"I'm as big a fan of dark matter and dark energy as anybody else," says astronomer Richard Ellis of Caltech. But, he adds, "I find it very worrying that you have a universe where there are three constituents, of which only one [i.e., ordinary matter] is really physically understood."

"When you teach undergraduates, and they say, 'Well, what is dark matter?' Well, nobody's really sure. 'What is dark energy?' We're even less sure. So you have to explain to a student, that … 90 percent of the universe, 95 percent, is in two ingredients that nobody really understands," says Ellis. "This isn't really progress."

No one argues that dark energy is difficult to comprehend. And as Trimble points out, it is hardly the first strange idea scientists have had to accept.

"It took two generations for people to be comfortable with quantum mechanics," she says. "The fact that you do not have good intuition about [dark energy] is true for quantum mechanics, general relativity, and lots of other things, because we can't easily mock them up in the laboratory."

And for cosmologists, dark energy has solved at least one cosmological conundrum raised by studies of the Cosmic Microwave Background, or CMB.

Next page: An infinitely expanding universe?

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"Outside the Box" Space and Terrestrial Transportation and Energy Technologies for the 21st Century

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"OUTSIDE THE BOX" SPACE AND TERRESTRIAL TRANSPORTATION AND ENERGY TECHNOLOGIES FOR THE 21ST CENTURY

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Abstract

This paper reviews the development of antigravity research in the US and notes how research activity seemed to disappear by the mid 1950s. It then addresses recently reported scientific findings and witness testimonies - that show us that this research and technology is alive and well and very advanced. The revelations of findings in this area will alter dramatically our 20th century view of physics and technology and must be considered in planning for both energy and transportation needs in the 21st century.

Historical Background

Townsend Brown's Technology of Electrogravitics[1]

In the mid 1920's Townsend Brown[2] discovered that electric charge and gravitational mass are coupled. He found that when he charged a capacitor to a high voltage, it had a tendency to move toward its positive pole. This became known as the Biefeld-Brown effect. His findings were opposed by conventional minded physicists of his time.

The Pearl Harbor Demonstration. Around 1953, Brown conducted a demonstration for military top brass. He flew a pair of 3-foot diameter discs around a 50-foot course tethered to a central pole. Energized with 150,000 volts and emitting ions from their leading edge, they attained speeds of several hundred miles per hour. The subject was thereafter classified.

Project Winterhaven. Brown submitted a proposal to the Pentagon for the development of a Mach 3 disc shaped electrogravitic fighter craft. Drawings of its basic design are shown in one of his patents. They are essentially large-scale versions of his tethered test discs.

Review of Issues From the 1950s

Once Brown's findings became well known, some scientists began to openly speak about the flying technology of UFOs, which had been observed extensively since the 1940s. None other than Professor Hermann Oberth, considered by some to be one of the fathers of the space age, who later worked in the US with Wernher von Braun, the Army Ballistic Missile Agency and NASA, stated the following in 1954:[3]

"It is my thesis that flying saucers are real and that they are space ships from another solar system." Perhaps of more interest to our present discussion on propulsion, he then stated that: "They are flying by the means of artificial fields of gravity... They produce high-tension electric charges in order to push the air out of their paths, so it does not start glowing, and strong magnetic fields to influence the ionized air at higher altitudes. First, this would explain their luminosity... Secondly, it would explain the noiselessness of UFO flight..." We now know that he was fundamentally correct in his assessment.

In 1956, a British research company, Aviation Studies (International) Ltd. published a classified report on Electrogravitics Systems examining various aspects of gravity control. They summarized the pioneering work of Townsend Brown and then described the use of electrogravitic thrust as follows:

"The essence of electrogravitics thrust is the use of a very strong positive charge on one side of the vehicle and a negative on the other. The core of the motor is a condenser and the ability of the condenser to hold its charge (the K-number) is the yardstick of performance. With air as 1, current dielectrical materials can yield 6 and use of barium aluminate can raise this considerably, barium titanium oxide (a baked ceramic) can offer 6,000 and there is a promise of 30,000, which would be sufficient for supersonic speed."[4]

In one of their conclusions, based on Brown's work, they suggested that: "Electrostatic energy sufficient to produce a Mach 3 fighter is possible with megavolt energies and a k of over 10,000."[5]

In spite of Brown's solid research, they later stated that, "One of the difficulties in 1954 and 1955 was to get aviation to take electrogravitics seriously. The name alone was enough to put people off."[6] It seems that is as true today as it was in the 1950s.

A report by another British company, Gravity Rand, Ltd. in 1956, agrees with this assessment and states: "To assert electrogravitics is nonsense is as unreal as to say it is practically extant. Management should be careful of men in their employ with a closed mind or even partially closed mind on the subject."[7]

However, a trade press magazine, The Aviation Report, made a numerous references to antigravity projects and listed many of the companies pursuing research in this area. Quotes from The Aviation Report listed in the Aviation Studies (International) Ltd. report[8] are suggestive of what was going on behind the scenes.

In 1954 they predicted that: "... progress has been slow. But indications are now that the Pentagon is ready to sponsor a range of devices to help further knowledge."... "Tentative targets now being set anticipate that the first disk should be complete before 1960 and it would take the whole of the 'sixties to develop it properly, even though some combat things might be available ten years from now." (Aviation Report 12 October 1954)[9]

During this time period many of the major defense and technology companies were cited as either having research projects or activities in this new field. For example: "Companies studying the implications of gravitics are said, in a new statement, to include Glenn Martin, Convair, Sperry-Rand, and Sikorsky, Bell, Lear Inc. and Clark Electronics. Other companies who have previously evinced interest include Lockheed, Douglas and Hiller." (Aviation Report 9 December 1955)[10].

Others of these reports mention: AT&T, General Electric, as well as Curtiss-Wright, Boeing and North American as having groups studying electrogravitics.

During the same time period, the Gravity Rand report notes that: "Already companies are specializing in evolution of particular components of an electogravitics disk."[11]

However, in the area of predictions, the Aviation Report stated the following based on an extrapolation of technology development: "Thus this century will be divided into two parts – almost to the day. The first half belonged to the Wright Brothers who foresaw nearly all the basic issues in which gravity was the bitter foe. In part of the second half, gravity will be the great provider. Electrical energy, rather irrelevant for propulsion in the first half becomes a kind of catalyst to motion in the second half of the century." (Aviation Report 7 September 1954).[12]

Looking back it is easy to say that they missed the mark. Did they really miss it by a half a century? Reading through these reports it is quite obvious that there was much interest in antigravity among a number of very high profile companies, as well as in the Department of Defense. What happened to this interest and why was it all downplayed during the following four plus decades? After all, T. Brown had shown that there is a demonstrable connection between high voltage fields and gravity. Why has it taken until the 1990s for more than just a few scientists to look at these results and publish on them in the open literature? A review of recent statements by former military personnel and civilians connected to covert projects begins to shed light on research activity in these areas over the last half century. And it appears that there had been significant breakthroughs during this time period, well shielded from both the scientific and public eye.

Recent Scientific Developments

In this section we consider developments in the antigravity field since the late 1980s and why the confluence of scientific findings and the testimony of witnesses associated with the military and covert groups indicates that a gravity solution with technological implications has been found.

Although general relativity has not been able to explain Brown's electrogravitic observations, or any other antigravity phenomenon, the recent physics methodology of quantum electrodynamics (QED), appears to offer the theoretical framework to explain electrogravitic coupling. Recent papers by members of the Institute for Advanced Study Alpha Foundation are putting a solid theoretical foundation onto the antigravity effects within the theory of electrodynamics and include papers by Evans[13] and Anastasozki et al.[14]

Earlier in a breakthrough paper in 1994, Alcubierre showed that superluminal space travel is, in principle, physically possible and will not violate the tenants of the theory of relativity[15]. Puthoff[16] later analyzed these findings in light of the present SETI (Search for Extraterrestrial Intelligence) paradigms that insist that we could not be visited by extraterrestrial civilizations because of the speed-of-light limitations dictated by the general relativity theory. He suggests that super-luminal travel is indeed possible. This leads to reduced-time interstellar travel and the possibility of extraterrestrial visitation, which our limited under-standing of physics and scientific arrogance has "forbidden" in some sectors for most of the 20th century.

The second aspect of these physics findings deals with the zero point or vacuum state energy shown by the Casimir effect, which predicts that two metal plates close together attract each other due to imbalance in the quantum fluctuations. The implications of this zero point or vacuum state energy are tremendous and are described in several papers by Puthoff[17] starting during the late 1980s. A detailed bibliography on this and similar topics is available on the WWWeb.[18] Bearden[19] and colleagues have also written extensively on the theoretical physics of zero point energy and additionally have described various technological means of extracting this energy (for example see the recent paper by Anastasozki et al.[20]). A theoretical book on zero point energy by Bearden will soon be available.[21] There is significant evidence that scientists since Tesla have known about this energy, but that its existence and potential use has been discouraged and indeed suppressed over the past half century or more. [22].

The coupling of the electrogravitic phenomena observations and the zero point energy findings are leading to a new understanding of both the nature of matter and of gravity. This is just now being discussed in scientific journals (though some evidence suggests that it has been understood for decades within the black project covert community). The question that is being addressed is: what keeps the universe running? Or more specifically, where do electrons get their energy to keep spinning around atoms? As electrons change state they absorb or release energy, and where does it come from? The simplistic answer is that it is coming from the vacuum state. Puthoff[23] describes the process as follows: "I discovered that you can consider the electron as continually radiating away its energy as predicted by classical theory, but SIMULTANEOUSLY ABSORBING a COMPENSATING AMOUNT of energy from the ever-present sea of zero-point energy in which the atom is immersed. An equilibrium between these two processes leads to the correct values for the parameters that define the lowest energy, or ground-state orbit (see "Why atoms don't collapse," NEW SCIENTIST, July 1987). Thus there is a DYNAMIC EQUILIBRIUM in which the zero-point energy stabilizes the electron in a set ground-state orbit. It seems that the very stability of matter itself appears to depend on an underlying sea of electromagnetic zero-point energy."

Furthermore, it appears that it is the spinning of electrons that provides inertia and mass to atoms. These theories, linking electron spin, zero point energy, mass, and inertia have been presented in a number of recent papers, such as those by Haisch[24] and colleagues and provide us with a possible explanation of the Biefield-Brown effect. It appears that an intense voltage field creates an electromagnetic barrier that blocks the atomic structure of an atom from interacting with the zero point field. This slows down the electrons, reducing their gyroscopic effect, and thus reducing atomic mass and inertia, making them easier to move around.

Evidence of Extensive Antigravity Technology

The B-2 Advanced Technology Bomber

In 1993, LaViolette wrote a paper[25] discussing the B-2 bomber and speculating on its probable antigravity propulsion system, based on a solid understanding of electrogravitics,[26] the aircraft's design and the materials used in its manufacture. It appears that the craft is using a sophisticated form of the antigravity principles first described by T. Brown. Support for this thesis came from the Aviation Week and Space Technology (March 9, 1992), which reported that the B-2 bomber electrostatically charges its leading edge and its exhaust stream. Their information had come from a small group of former black project research scientists and engineers suggesting the B-2 utilizes antigravity technology. This information was supported by Bob Oechsler, an ex-NASA mission specialist who had publicly made a similar claim in 1990. These findings support the contention that there have been major developments in the area of antigravity propulsion which are presently being applied in advanced aircraft.

LaViolette later states the obvious that "the commercial airline industry could dramatically benefit with this technology which would not only substantially increase the miles per gallon fuel efficiency of jet airliners, but would also permit high-speed flight that would dramatically cut flight time."[27]

The Disclosure Project Witnesses

On May 9, 2001 a private organization, "The Disclosure Project"[28] held a press conference at the National Press Club in Washington DC. They presented nearly two dozen witnesses including retired Army, Navy and Air Force personnel, a top FAA official, members of various intelligence organizations including the CIA and NRO, and industry personnel, all of whom who had witnessed UFO events or had inside knowledge of government or industrial activities in this area. They also produced a briefing document[29] for members of the press and Congress and a book[30] which includes the testimony of nearly 70 such witnesses from a pool of hundreds. Although they all spoke of the reality of the UFO phenomena, many also spoke of covert projects dealing with antigravity, zero point energy technologies and development of alien reproduction vehicles (ARVs) by US black project and covert interests. The following excerpted quotes from these witnesses support the above contentions.

Dan Morris[31] is a retired Air Force career Master Sergeant who was involved in the extraterrestrial projects for many years. After leaving the Air Force, he was recruited into the super-secret National Reconnaissance Organization (NRO), during which time he worked specifically on extraterrestrial-connected operations. He had a cosmic top-secret clearance (38 levels above top secret) which, he states, no U.S. president, to his knowledge, has ever held.

"UFOs are both extraterrestrial and man made. Well, the guys that were doing the UFOs, they weren't sleeping, and Townsend Brown was one of our guys who was almost up with the Germans. So we had a problem. We had to keep Townsend Brown - what he was doing on anti-gravity electromagnetic propulsion secret." He then describes a type of zero point energy device.

"Well, if you have one of these units that's about sixteen inches long and about eight inches high and about ten inches wide, then you don't need to plug into the local electric company. These devices burn nothing. No pollution. It never wears out, because there are no moving parts. What moves are electrons, in the gravity field, in the electronic field, and they turn in opposite directions, okay?"

"Dr. B."[32] (name withheld since he still works in this area) is a scientist and engineer who has worked on top-secret projects almost all his life. Over the years he has directly worked on or had involvement with such projects involving anti-gravity, chemical warfare, secure telemetry and communications, extremely high-energy space based laser systems, and electromagnetic pulse technology.

"Anti-gravity. As a matter of fact, I used to go out to the Hughes in Malibu. They had a big think tank up there. Big anti-gravity projects; I used to talk to them out there. I'd give them ideas, because they bought all my equipment. But the American public will never, never hear about that." . . . "This flying disc has a little plutonium reactor in it, which creates electricity, which drives these anti-gravity plates. We also have the next level of propulsion, it is called virtual field, which are called hydrodynamic waves..."

Captain Bill Uhouse[33] served 10 years in the Marine Corps as a fighter pilot, and four years with the Air Force at Wright-Patterson AFB as a civilian doing flight-testing of exotic experimental aircraft. Later, for the next 30 years, he worked for defense contractors as an engineer of antigravity propulsion systems: on flight simulators for exotic aircraft - and on actual flying discs.

"I don't think any flying disc simulators went into operation until the early 1960s - around 1962 or 1963. The reason why I am saying this is because the simulator wasn't actually functional until around 1958. The simulator that they used was for the extraterrestrial craft they had, which is a 30-meter one that crashed in Kingman, Arizona, back in 1953 or 1952."

"We operated it with six large capacitors that were charged with a million volts each, so there were six million volts in those capacitors." . . . "There weren't any windows. The only way we had any visibility at all was done with cameras or video-type devices." . . ."Over the last 40 years or so, not counting the simulators - I'm talking about actual craft - there are probably two or three-dozen, and various sizes that we built."

"A.H."[34] formally of Boeing Aerospace, is a person who has gained significant information from inside the UFO extraterrestrial groups within our government, military, and civilian companies. He has friends at the NSA, CIA, NASA, JPL, ONI, NRO, Area 51, the Air Force, Northrup, Boeing, and others.

"Most of the craft operate on antigravity and electrogravitic propulsion. We are just about at the conclusion state right now regarding antigravity. I would give it maybe about 15 years and we will have cars that will levitate using this type of technology. We're doing it up at Area 51 right now. That's some of the stuff that my buddy worked on up at Area 51 with Northrup, who lives now in Pahrump, Nevada. We're flying anti-gravity vehicles up there and in Utah right now..."

Lieutenant Colonel Williams[35] entered the Air Force in 1964 and became a rescue helicopter pilot in Vietnam. He has an electrical engineering degree and was in charge of all the construction projects for the Military Air Command. During his time in the military he knew that there was a facility inside of Norton Air Force Base in California that no one was to know about.

"There was one facility at Norton Air Force Base that was close hold - not even the wing commander there could know what was going on. During that time period it was always rumored by the pilots that that was a cover for in fact the location of one UFO craft."

Note that all he knew was of the rumor, however, it is confirmed by the next testimony, which also confirms some of the comments made by Captain Uhouse.

Mark McCandlish[36] is an accomplished aerospace illustrator and has worked for many of the top aerospace corporations in the United States. A colleague, with whom he studied, has been inside a facility at Norton Air Force Base, where he witnessed alien reproduction vehicles, or ARVs, that were fully operational and hovering. He states that the US not only has operational antigravity propulsion devices, but we have had them for many, many years, and they have been developed through the study, in part, of extraterrestrial vehicles over the past fifty years.

A close friend, Brad Sorensen, told him of visiting The Big Hangar, during an air show at Norton Air Force Base on November 12, 1988 and how he had seen flying saucers in this hangar. "There were three flying saucers floating off the floor—no cables suspended from the ceiling holding them up, no landing gear underneath—just floating, hovering above the floor. He said that the smallest was somewhat bell-shaped. They were all identical in shape and proportion, except that there were three different sizes. They had little exhibits with a videotape running, showing the smallest of the three vehicles sitting out in the desert, presumably over a dry lakebed, some place like Area 51. It showed this vehicle making three little quick, hopping motions; then [it] accelerated straight up and out of sight, completely disappearing from view in just a couple of seconds—no sound, no sonic boom—nothing."

"Well, this craft was what they called the Alien Reproduction Vehicle; it was also nicknamed the Flux Liner. This antigravity propulsion system—this flying saucer—was one of three that were in this hangar at Norton Air Force Base. [Its] synthetic vision system [used] the same kind of technology as the gun slaving system they have in the Apache helicopter: if [the pilot] wants to look behind him, he can pick a view in that direction, and the cameras slew in pairs. [The pilot] has a little screen in front of his helmet, and it gives him an alternating view. He [also] has a little set of glasses that he wears—in fact, you can actually buy a 3-D viewing system for your video camera now that does this same thing—so when he looks around, he has a perfect 3-D view of the outside, but no windows. So, why do they have no windows? Well, it's probably because the voltages that we're talking about [being] used in this system were probably something between, say, half a million and a million volts of electricity." Brad Sorensen stated that at the ARV display, "a three star general said that these vehicles were capable of doing light speed or better."

All of these witness testimonies do not prove the existence of a successful US covert program in antigravity technologies. Only the demonstration of such craft coupled with the accompanying government and technical specification documents would 'prove' this. However, these testimonies coupled with information from other substantial sources such as Nick Cook's new book mentioned below, strongly supports this contention.

The Hunt for Zero Point[37]

Although this very recent book (August, 2001) is not yet available in the US, it contains some of the strongest evidence yet for major efforts and success in the field of antigravity technology. The author, Nick Cook, who for the past 15 years has been the Aviation Editor and Aerospace Consultant for Jane's Defense Weekly, spent the last 10 years collecting information for the book. This included archival research on Nazi Germany's antigravity technology and interviews with top officials at NASA, the Pentagon and secret defense installations. He shows that America has cracked the gravity code and classified the information at the highest security levels. Because antigravity and its allied zero point energy technologies potentially offer the world a future of unlimited, non-polluting energy it has been suppressed because of the "huge economic threat". His findings support those reported by many of the Disclosure Project witnesses cited above.

Antigravity Technology Demonstrations

Although T. Brown reported many of his findings nearly a half century ago, other experimenters have just recently begun to reproduce his work and report it in the open literature and on the WWWeb. For example, Davenport[38] published the results of his work in 1995 supporting the findings of T. Brown. More recently, Transdimensional Technologies[39] in the USA and J. Naudin[40] labs in France have posted on the WWWeb: diagrams, web videos, and data on their versions of antigravity "Lifters" based on an extension of Brown's work. It is a sad commentary on this whole area of research to see that public science is requiring us to demonstrate principles that were demonstrated nearly fifty years ago.

There have also been a number of other demonstrations of "antigravity" phenomena by researchers throughout the world. This includes the work of Brazilian physics professor, Fran De Aquino, and such devices as: the Searl Electrogravity Disc, the Podkletnov Gravity Shield and Project Greenglow, the Zinsser Kineto-baric Field Propulsion and the Woodward Field Thrust Experiments on Piezoelectrics. All of these are described in more detail by Greer and Loder.[41]

Implications of This Research

• Antigravity and zero point energy research and their applications are finally being addressed by some of the open scientific community. This means there will have to be a rewriting of textbooks in this area so our new generation of students can apply this "new knowledge." Its application will lead to major breakthroughs in transportation technologies both earthside and in outer space. The implications are that we have the potential for human exploration of our solar system and beyond, if we have the will, within our lifetimes. It also means that the majority of 20th century space technology will be obsolete and in fact may already be so.

• The zero point or vacuum state energy source is seen as a totally non-polluting energy source, which has the potential to replace all the fossil fuels on this planet. It also will provide the energy needed for long range space flights. This means that fuel cells and solar cells in common use today for space flight energy applications will only be needed until we transition to these new energy technologies.

• Based on an analysis of trends in antigravity research over the last half-century and the information provided by numerous witnesses, it appears that there is both good and bad news. The good news is that it appears that we (at least covert projects) have already developed the theories of antigravity, and additionally have developed working spacecraft based on these principles. The bad news is that these technologies have been developed for at least several decades, at the public's expense and that human kind has been deprived of these technologies, while continuing to waste energy using less efficient and pollution enhancing technologies.

Supporting this contention is the following quote from Ben Rich, former head of the Lockheed Skunkworks. Just prior to his death, he stated to a small group after a lecture that: "We already have the means to travel among the stars, but these technologies are locked up in black projects and it would take an act of God to ever get them out to benefit humanity..." He further went on to say that, 'anything you can imagine we already know how to do.' Strong words from a knowledgeable deep insider and words that support what a number of the witnesses stated as well.

• As the reality of this knowledge begins to be understood, there will be an outcry among space scientists not on the inside for release of these technologies to allow all of us to explore space. There will be major changes in the way that NASA does its business, though predicting these changes is difficult.

• Not only has space exploration in the public sector suffered, but our planet's environment has suffered as well. Thus as this knowledge begins to sink in there will be an outcry among all concerned citizens on this planet for release of these technologies to allow all of us to reduce and ultimately eliminate global warming and environmental pollution that so threatens our way of life. These technologies will not only affect space travel technologies, but will also have a profound effect on transportation and energy production on the earth's surface.

• In conclusion, we might consider the observation made by Halton Arp[42]:

"We are certainly not at the end of science.
Most probably we are just at the beginning!"

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Some Observations on Avoiding Pitfalls in Developing Future Flight Systems

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SOME OBSERVATIONS ON AVOIDING PITFALLS IN DEVELOPING FUTURE FLIGHT SYSTEMS

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Abstract

A number of programs and concepts have been proposed to achieve breakthrough propulsion. As an cautionary aid to researchers in breakthrough propulsion or other fields of advanced endeavor, case histories of potential pitfalls in scientific research are described. From these case histories some general characteristics of erroneous science are presented. Guidelines for assessing exotic propulsion systems are suggested. The scientific method is discussed and some tools for skeptical thinking are presented. Lessons learned from a recent case of erroneous science are listed.

Introduction

Over the past few years a number of speculative propulsion/transportation ideas have been advanced which, if they can be verified, promise to revolutionize space transportation.[1-4] In addition, a question has been asked and some proposed answers given on the possible propulsion system(s) for unidentified flying objects (UFOs) or "flying saucers", if the existence of UFOs is accepted.[5,6] Researchers at the U.S. Air Force (USAF) Phillips Laboratory have proposed research into "... more advanced ideas ... [such as]... fundamental physics concepts which require basic research and/or substantial development to create some sort of breakthrough. These include vacuum zero point energy, energetic species (i.e. nuclear or electronic metastables), ball lightning, and various 'breakthrough physics' concepts. In addition, a number of new emerging technologies and popular ideas will be followed such as nanotechnology, above unity devices, and cold fusion".[7]

Separately, NASA has recently initiated a "breakthrough propulsion physics" program which "... implies discovering fundamentally new ways to create motion, presumably by manipulating inertia and gravity or by harnessing other interactions of matter, fields and space-time".[8,9]

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Given the speculative proposals and the interest in developing breakthrough propulsion systems it seems prudent and appropriate to review some of the pitfalls that have befallen other programs in "speculative science" so that similar pitfalls can be avoided in the future. And, given the interest in UFO propulsion, some guidelines to use in assessing the reality of UFOs will also be presented.

This paper will summarize some of the principal areas of "speculative science" in which researchers were led astray and it will then provide an overview of guidelines which, if implemented, can greatly reduce the occurrence of errors in research.

Some Case Histories of Errors in Science

This section will briefly describe several case histories involving errors in science: (1) N rays; (2) Davis and Barnes experiment; (3) polywater; (4) infinite dilution; and (5) cold fusion.

N Rays

In 1903, French physicist René-Prosper Blondlot claimed to have discovered that by heating a filament inside an iron tube containing an aluminum-covered opening one could see faintly illuminated objects better in a darkened room. Some of his early experiments were performed with pieces of paper which were barely illuminated by a glowing calcium sulfide screen or a lamp shining through pinholes. Since the heated filament inside the iron tube improved the viewing, Blondlot concluded that a new type of ray was being produced, a ray which was stopped by the iron but not by the aluminum. He called this new ray an "N ray" to honor the University of Nancy, where he worked.[10]

Blondlot discovered that certain objects could be made to store these N rays. For example, if a brick was wrapped in black paper and exposed to sunlight it would give off N rays when taken back into the darkened laboratory. Blondlot noted that if the brick was held close to one's head it made it easier to see the paper in the darkened room. Holding the brick near the paper had a similar effect.[10]

Blondlot reported that the N rays had some odd effects. For example there was no improvement in the effect of improved illumination if more than one brick was used. Loud noises (such as someone entering the laboratory) could spoil the effect. Heat increased the effect but Blondlot said N rays were not the same as heat. Blondlot also claimed to have found negative N rays, which he called N' rays that could nullify the effect of the N rays. It was necessary to spend some time in the darkened room to see the effect.[10]

Blondlot published a number of papers on N rays. Other scientists also published papers with about half confirming Blondlot's work.[10]

The American physicist R. W. Wood visited Blondlot to witness some of the N ray experiments. Wood watched as Blondlot used a large aluminum prism with a 60° angle to measure the refractive index of the N rays to two or three significant figures.[10]

When Wood questioned Blondlot as to how he could measure the position of the beam to within 0.1 mm when the slits in the Nernst filament were 2-mm wide, Blondlot replied to the effect "That's one of the fascinating things about the N rays. They don't follow the ordinary laws of science that you ordinarily think of".[10]

At Wood's request, Blondlot repeated the experiments; however, unbeknownst to Blondlot in the darkened room, Wood had removed the aluminum prism. Blondlot got the same measurements! Wood subsequently published this result, effectively ending the era of the N rays.[10]

Later some German researchers investigated how Blondlot had been deceived. They observed that in a darkened room it is difficult to see the paper so one is tempted to pass one's hand in front of the paper to see if the paper is being illuminated. The interesting result the German researchers found was that the hand could be "observed" whether it was in front of the paper or behind it. Langmuir has remarked that this "... is the natural thing, because this is a threshold phenomenon. And a threshold phenomenon means that you don't know, *you really don't know*, whether you are seeing it or not. But if you have your hand there, well, of course, you see your hand because you *know* your hand's there and that's just enough to win you over to where you know that you see it. But you know it just as well if the paper happens to be in front of your hand instead of in back of your hand, because you don't know where the paper is but you *do* know where your hand is".[10]

The phenomenon of accepting a false belief and then continuing to defend it in the face of information showing the falsity of the belief is not new. In a landmark study published in 1956 it was stated that "A man with a conviction is a hard man to change. Tell him you disagree and he turns away. Show him facts or figures and he questions your sources. Appeal to logic and he fails to see your point".[11] As this study demonstrated, showing someone unequivocal and undeniable evidence that a person's belief is wrong means "The individual will frequently emerge, not only unshaken, but even more convinced of the truth of his beliefs than ever before. Indeed, he may even show a new fervor about convincing and converting other people to his view".[11]

Davis and Barnes Experiment

Around 1930, two American physicists, Bergen Davis and Arthur Barnes conducted a series of experiments in which electrons from a hot filament were accelerated to match the speed of alpha particles being emitted from a polonium source. By carefully adjusting the voltage used to accelerate the electrons the experimenters claimed that they could cause the electrons to be captured by the alpha particles. The measurements were made in a darkened room by counting the number of scintillations on a zinc sulfide screen with a microscope. To save time, the experiments were focused on the voltages where it was calculated that the peaks should occur according to the Bohr theory. Davis and Barnes claimed to be able to achieve electron capture at each of the energy levels of the Bohr theory of the helium atom with measured accuracies of 0.01 volts.[10]

Irving Langmuir and Willis R. Whitney (then both at the General Electric Research Laboratory in Schenectady, New York) visited the Columbia University laboratory of Davis and Barnes and witnessed some of the experiments. They found that Barnes was not counting for a fixed two minutes as claimed and that he was ruling out some counts arbitrarily. When Langmuir secretly had the technician try a wider range of voltages Barnes got measurements that no longer correlated with the Bohr energy levels. Barnes had an *ad hoc* excuse for every criticism Langmuir raised about the way the experiments were being conducted.[10]

Langmuir, who was to earn the 1932 Nobel Prize in chemistry, subsequently wrote Barnes a 22-page letter giving Barnes all the data obtained by Whitney and himself "... and showing really that the whole approach to the thing was wrong; [Barnes] was counting hallucinations, which I find is common among people who work with scintillations if they count for too long. Barnes counted for six hours a day and it never fatigued him. Of course it didn't fatigue him, because it was all made up out of his head".[10] The next year Davis and Barnes admitted in a short article in *Physical Review* that they hadn't been able to reproduce the effect. They noted that the scintillations they were measuring were a threshold phenomenon.[10]

Polywater

In the 1960s and early 1970s reports from N. N. Fedyakin of the Kostrama Polytechnical Institute of the former Soviet Union and Boris V. Derjaguin of the Institute of Physical Chemistry of the Academy of Sciences of the former Soviet Union claimed there was a new form of water, later called polywater, that was more dense and viscous than normal water. Polywater, which was claimed to be formed in capillary tubes in an atmosphere nearly saturated with water, reportedly froze at -50 °C and boiled near 300 °C. Infrared spectroscopy showed that polywater produced a spectrum entirely different from normal water. Many papers were published on polywater and several theories were developed.[12]

As part of a study of polywater, Denis L. Rousseau and Sergio Porto, then at the University of Southern California, irradiated a sample of polywater with a laser to obtain a Raman spectrum. The laser turned the polywater into a black char, indicating that it "... was no polymer of water but more likely a carbonaceous material".[12] Whenever negative results like these were obtained, the proponents of polywater would always claim that the samples giving the negative results were contaminated but that their own samples, which showed polywater, were clean. Rousseau later showed that one could obtain the infrared spectrum for polywater from ordinary human sweat. This showed "... that polywater is not water at all but a product of organic contamination in the capillary tubes".[12]

Rousseau subsequently observed that "The polywater episode illustrates the loss of objectivity that can accompany the quest for great new discoveries. The quantities of polywater available were so small that many useful experiments could not be done. Many theories were put forward to describe the structure of polywater without even considering the thermodynamic difficulty of accounting for its very existence. Finally, definitive experiments showing high levels of contamination were done but not accepted, until overwhelming evidence showed that a new polymer of water had not been discovered".[12]

Infinite Dilution

In 1988 Jacques Benveniste of the University of Paris and his collaborators reported that water retained a memory or template of a molecule even when there should be no molecules present. This phenomenon is referred to as "infinite dilution" meaning that a biological effect is produced even when the "... biologically active solution is diluted so many times that no active molecules can be present ..."[12]

After Benveniste's paper was published in *Nature*, John Maddox, the editor of *Nature*, James Randi (a professional magician), and Walter Stewart (an experienced fraud investigator) spent three weeks in Benveniste's laboratory witnessing the experiments. When an elaborate series of double-blind experiments were conducted the biological effect was not measured. This committee of three reported "... that the original experiments were poorly controlled and that no effort had been made to exclude systematic error or observer bias".[12]

Many of the traits reported in the earlier episodes of erroneous science were present with infinite dilution. The effect was weak and independent of the causative agent. The counting was done visually and it was extremely difficult to do. When the control produced results at variance with the experimenters's beliefs the counting was redone. Negative results were overlooked. Sometimes experiments would not work for several months and one investigator seemed to be the best at making the experiments work.[12]

Rousseau has written that "Benveniste and his colleagues were not doing fraudulent work. They observed the effects that they reported. But they so believed in the phenomenon that they could ignore or reinterpret any questionable findings. In replying to the Maddox committee, Benveniste wrote, 'It may be that all of us are wrong in good faith. This is no crime but science as usual and only the future knows.' But, self-delusion is not science as usual".[12]

Cold Fusion

In 1989 two research groups in Utah announced that they had discovered cold fusion by means of simple electrochemical cells. Both research groups used heavy water although their salts were different. The heavy water would split into deuteroxyl ions (OD^-) and deuterons when a current was passed through the cells. What they hoped to achieve was to collect enough deuterons at the palladium cathode to cause them to pack so tightly that they would fuse at room temperature and release energy, a process normally requiring temperatures on the order of 10^8 °C.[12]

B. Stanley Pons of the University of Utah and Martin Fleischmann of the University of Southampton reported achieving enough cold fusion that the thermal output exceeded the energy input by 4.5 times. To explain away the absence of the neutrons which should have been present at a level sufficient to kill the experimenters they reported that "... the bulk of the energy release is due to a hitherto unknown nuclear process".[12] It was later learned that their electrochemical cell was not a closed system so they did not have a good heat balance. Moreover, their method of calculating the energy release was flawed.[13,14]

David E. Williams, the Thomas Graham Professor of Chemistry at University College London and previously a research group leader at the Harwell Laboratory of the U.K. Atomic Energy Authority responsible for that laboratory's attempts to verify cold fusion, has written about one staunch advocate of cold fusion repeating "... the common assertion that the excess energies associated with the electrolysis of D_2O with a Pd cathode are on the order of tens to hundreds of MJ/cm^3 and hence can only find an explanation in some phenomenon outside the chemistry of the system. In this he displays an ignorance of the experimental measurement and a naive belief in the significance of impressively large numbers. The great majority of experiments measure power; the large numbers are obtained by multiplying an (often small) power by a large time (the duration of the experiment) and dividing by a small volume (that of the Pd cathode). In comparison with the total energy applied to the electrolytic cell, the excesses are much less impressive, on the order of a few percent. More properly, in comparison with the power applied to the cell, the claimed excess power is often also small ...".[15]

Steven Jones of Brigham Young University and his collaborators found evidence of increased neutron production but nothing like the heat output reported by Pons and Fleischmann.[12]

Other researchers were unable to duplicate the experiments of the two Utah groups. The neutron emissions measured by Pons and Fleischmann were inferred from a gamma-ray emission spectrum that was more narrow than the resolution of their detector. The claim that tritium, one product of a deuteron-deuteron fusion reaction, had been found was later discredited when it was learned that tritium was a contaminant in the palladium electrode.[12]

As Rousseau has summarized it, "Cold fusion was doomed from the start when a race to be first took precedence over the desire to be right. Most measurements reporting nuclear effects from cold fusion were barely above the background noise, and extended periods of failed experiments afflicted even Pons's laboratory. The proponents of cold fusion attributed the failure to several causes: differences in the materials, the size of the electrodes, impurities in the electrodes, and low current density. The list goes on.

"Nuclear reactions, however, are very well understood. Any theory offered to account for the reported observations must postulate new nuclear processes that only occur in the palladium electrodes ... The investigators of cold fusion also ignored definitive experiments".[12]

The whole sorry episode of cold fusion, which the co-chair of the Department of Energy Energy Research Advisory Board panel on cold fusion, Professor John R. Huizenga, has termed the "scientific fiasco of the century", has been well documented in Refs. 13,14, 16-18. Suffice it to say that it is not a pretty picture but as Prof. Huizenga stated: "The cold fusion fiasco illustrates once again that the scientific process works by exposing and correcting its own errors".[13]

Despite all these problems the U.S. Air Force has considered studying (as noted earlier) "... a number of new emerging technologies and popular ideas ... such as nanotechnology, above unity devices, and cold fusion".[7] Some USAF personnel apparently foresee using cold fusion for satellite power and for fast acting thrusters for survivability. The payoffs are listed as (1) lower weight; (2) near limitless source of heat; (3) high reliability and operability; and (4) simplicity and robustness. The only technology needs identified were the scaling up of cold fusion and the development of specialized pumps, valves, and nozzles.[7] The fact that no reputable, objective scientist has been able to prove the existence of cold fusion seems to be beside the point! (Even NASA got in the cold fusion act briefly in response to the NASA Administrator's order that no nuclear power sources be flown again on NASA spacecraft. After researchers at Lewis Research Center were unable to make cold fusion work and mission planners at the Jet Propulsion Laboratory showed to the Administrator's satisfaction that there wasn't much sunlight in the outer Solar System he recanted his order against nuclear power although he does want a more sporty -- and possibly unachievable within current funding and schedule limits -- conversion system for the next generation of radioisotope power sources.)

As shown by the original hullabaloo over cold fusion and the more recent NASA activities followed by the proposed USAF program, an unfortunate aspect to bad science such as cold fusion is that it diverts time and funding from real science. Science writer Gary Taubes has written that "What cold fusion had proven, nonetheless, was that the nonexistence of a phenomenon is by no means a fatal impediment to continued research. As long as financial support could be found, the research would continue. And that support might always be found so long as the researchers could obtain positive results. In fact, the few researchers still working in the field would have little incentive to acknowledge negative results as valid, because such recognition would only cut off their funds. It promised to be an endless loop".[14]

Something like this has certainly occurred with thermionic reactor research in the U.S. where hundreds of millions of dollars have been spent yet no long-lived (>5 years), high efficiency (≥10%), high specific power (>5.5 We/kg) in-reactor-core thermionic system has been built in the U.S.[19-21] Still the studies continue, now with a focus on bimodal power/propulsion systems.[22] And despite the investment of over $500 million in today's dollars with no U.S. in-core thermionic reactor being built and meeting the aforementioned goals, General Atomics of San Diego, California was recently awarded a $5.4 million cost-plus-fixed-fee contract by the Defense Special Weapons Agency "... for the research, development, test and evaluation of advanced in-core thermionic technologies to support long duration space missions for national security purposes. Focus is on the advancement of thermionic performance rather than an overall system design improvement *since no specific mission has yet been identified on which to base detailed system requirements*"[emphasis added].[23] Given the end of the Cold War and the lack of military reactor missions coupled with the lack of any real progress in U.S. in-core thermionic research it is doubtful if there will ever be any real military system requirements but contracts will continue to be awarded in an "endless loop". Is this pathological science or pork barrel politics -- or both?

Symptoms of Pathological Science

On 18 December 1953, Nobel-laureate Irving Langmuir gave a colloquium on the subject of what he termed "pathological science", the science of things that aren't so. As Langmuir stated it, "These are cases where there is no dishonesty involved but where people are tricked into false results by a lack of understanding about what human beings can do to themselves in the way of being led astray by subjective effects, wishful thinking or threshold interactions".[10]

Based on his study of the Davis and Barnes experiment, the incident of the N rays and other early mistakes, Langmuir listed six symptoms of pathological science:[10]

- *The maximum effect that is observed is produced by a causative agent of barely detectable intensity, and the magnitude of the effect is substantially independent of the intensity of the cause.*

- *The effect is of a magnitude that remains close to the limit of detectability or, many measurements are necessary because of the very low statistical significance of the results.*

- *There are claims of great accuracy.*

- *Fantastic theories contrary to experience are suggested.*

- *Criticisms are met by* ad hoc *excuses thought up on the spur of the moment.*

- *The ratio of supporters to critics rises up to somewhere near 50% and then falls gradually to oblivion.*

Working with more recent erroneous science such as polywater, infinite dilution and cold fusion, Denis L. Rousseau, at the time a Distinguished Member of the Technical Staff at AT&T Bell Laboratories, condensed Langmuir's six symptoms into two characteristics and added a third, which he believes to be the most important:[12]

1. *The effect being studied is often at the limits of detectability or has a very low statistical significance.*

2. *There is a readiness to disregard prevailing ideas and theories.*

3. *The investigator finds it nearly impossible to do the critical experiments that would determine whether or not the effect is real.*

In looking at the cases of pathological science presented in this paper it is clear that most of them are at the limits of detectability and they often were based on subjective visual observations. The fact that there may be no direct connection between the causative agent (e.g., number of hot bricks supposedly emitting N rays) and the effect (better viewing) is not seen as an impediment to the "new" scientific "discovery". News accounts of the advertised anti-gravity effect also place the effect at the limits of detectability.[1,2]

Cold fusion represents perhaps the most extreme example of concocting new theories to explain a poorly understood and poorly conducted set of experiments.[13,14] In contrast to the ready belief of the cold fusion proponents in the fantastic new physics invoked to explain their results, the author found it refreshing to hear from several of the original nuclear fission researchers (who were coincidentally meeting in a special 50th anniversary conference at the same time as the cold fusion fiasco erupted) that they were unwilling to accept their experimental results until all other avenues had been explored.[24] Would that other researchers had been as careful!

In none of the examples considered in the previous section did the researchers conduct experiments to determine if their results could be wrong. And in those cases where other researchers came to different conclusions they were criticized for having made mistakes or using bad samples or the wrong procedures.

Carl Sagan has written about people who make extraordinary claims, "The burden of proof is on them, not on those who might be dubious".[25] In short, if someone believes he/she has discovered cold fusion or anti-gravity it is up to him/her to prove it beyond a shadow of doubt. It is not up to the skeptics to disprove it. Unfortunately, as Sagan has observed pseudoscience operates just the opposite from normal science: "Hypotheses are often framed precisely so they are invulnerable to any experiment that offers a prospect of disproof, so even in principle they cannot be invalidated. Practitioners are defensive and wary. Skeptical scrutiny is opposed. When the pseudoscientific hypothesis fails to catch fire with scientists, conspiracies to suppress it are deduced".[26]

As Sagan has so eloquently put it, "I believe that the extraordinary should certainly be pursued. But extraordinary claims require extraordinary evidence".[25] To date the extraordinary evidence has not been reported for cold fusion or anti-gravity.

Guidelines for Assessing Other Exotic Propulsion Systems

One writer has pondered the question of what sort of propulsion system a UFO would have to have to match the reported observations of the motions of so-called flying saucers.[5,6] Even though people have seen strange things in the sky for centuries, the "Age of Confusion" about flying saucers began with the sighting near Mount Rainier by private pilot Kenneth Arnold on 24 June 1947.[27] Following Arnold's claimed sighting there have been thousands of reports of strange craft in the skies.[27,28]

Unfortunately, the sightings remain for the most part anecdotal and the photographs are generally suspect. Supposed artifacts have been shown to be of terrestrial manufacture. In short, while there remain some unexplained episodes, the vast majority of "sightings" are of natural phenomena or they are delusions or hoaxes.[25-28]

Astronomer Alan Hale, who is co-discoverer of Comet Hale-Bopp and director of the Southwest Institute for Space Research, has listed three basic principles as guides he uses in confronting beliefs about UFOs or other paranormal phenomena:[29]

1. *Extraordinary claims require extraordinary evidence.*

As an example of the kind of extraordinary evidence he is seeking, Hale lists "... the actual physical aliens themselves, where I and other trustworthy and competent scientists and individuals can study and communicate with them. I'd like to examine their spacecraft and learn the physical principles under which it operates. I'd like a ride on that spacecraft."[29] And he lists other things he would like to see and investigate directly.

Personally, I would like to see the UFO land on the Mall in Washington, D.C. and be subjected to a complete inspection using all the resources (scientists, engineers, technicians, equipment, etc.) at humanity's disposal. Like Sagan [25,26], I am highly skeptical about these reported aliens in UFOs since they never seem to contact any officials, they never demonstrate or leave any technology we don't already have and they never leave any messages that we don't already know.

2. *The burden of proof is on the positive.*

Hale demands that the one making the claim produce the extraordinary evidence to prove the correctness of the claim, noting that the burden is not on the skeptic to prove that the advocate is wrong. He goes on to state that "... you must prove your case by providing the direct and compelling evidence for it; you can't prove it by eliminating a few token explanations and then crying, 'Well, what else can it be?'"[29]

3. *Occam's Razor: If one is confronted with a series of phenomena for which there exists more than one viable explanation, one should choose the simplest*

explanation which fits all the observed facts.

Hale notes that people can make mistakes in their observations and that most people are not aware of the natural phenomena one can observe in the sky. Many people are not trained to observe what they claim to observe. People can be deceived by their preconceived notions and expectations and some people will create hoaxes. Hale asserts that "Taking all these undeniable facts together, the simplest explanation--to me, anyway--for the UFO phenomenon is that every report is either a hoax or is a mistake of some sort. If this explanation is incorrect, then you have to increase the sphere of undeniable facts; and for this, see points 1) and 2) above".[29]

Another "breakthrough physics" concept being studied is based on the belief that energy can be extracted from the zero-point fluctuations of the vacuum.[7] In searching for the origin of this idea, R. L Park of the American Physical Society wrote that "'The New Energy News' ... credits the idea to physicist Harold E. Puthoff and proclaimed him 'The New Energy News Theorist of the Year.' ... Puthoff's ideas are controversial; but he's accustomed to controversy. In 1972, at the Stanford Research Institute, Puthoff and Russell Targ were promoting psychic spoon-bender Uri Geller; five years later, they published 'Mind Reach,' a book about remote-viewing that inspired the CIA to invest in psychic espionage. Reportedly, Puthoff himself once sent his mind to explore the surface of planet Mercury".[30] Clearly, Hale's principles should be applied to this type of research!

Author's Note: For those not familiar with the *New Energy News*, it has been published by something called the Fusion Information Center which also disseminated information on cold fusion. This publication states that it is interested in "... papers ... covering both theory and practice of energy producing devices and systems such as cold nuclear fusion, rotating N-Machines, Solid-State energy systems, Magnetic over-unity machines, Tapping Space Energy (Zero-Point Energy), gravity control techniques, energetic transmutations (nuclear reactions), and other new energy research".[31] Those interested in some of the activities of Harold Puthoff, Russell Targ and the spoon-bender Uri Geller are encouraged to read *Science, Good, Bad and Bogus* by Martin Gardner.[32]

The Scientific Method

Physicist Alan Cromer has described science as "... the search for a consensus of rational opinion among all competent researchers ... The products of science give empirical proofs of its theories. Mathematics and experimentation provide powerful arguments with which to convince and persuade".[33] Cromer states that "Science is the heretical belief that the truth about the real nature of things is to be found by studying the things themselves".[33] Cromer also notes that the scientific way of thinking is not natural to humans; it is something which has to be learned.[33] Sagan has observed that "Science is a way of thinking much more than it is a body of knowledge".[25]

To study things requires the use of the scientific method. While there is no single absolute detailed process to be followed for all science, the American philosopher Morris R. Cohen has written that "The problem of how to get rid of illusion and see what truly goes on in nature requires that persistent and arduous use of reason which we call scientific method ... Scientific method is a systematic effort to eliminate the poison of error from our common knowledge".[34] In short, science is as much a process as it is an assembly of facts, but it is a process that requires assembling of the relevant facts (quantitative measurements) and the testing of hypotheses. It is a process that any scientist in the field should be able to duplicate in order to check claims of new discoveries.[25,26,29,32-35]

To aid in avoiding pitfalls in developing advanced propulsion (or exploring any new field), Sagan's tools of skeptical thinking are highly recommended:[26]

- *Obtain independent confirmation of the "facts".*
- *"Encourage substantive debate on the evidence by knowledgeable proponents of all points of view."*
- *Give little weight to arguments from authority.*
- *Develop and test more than one hypothesis in a fair and objective manner.*
- *Do not become overly attached to your own hypothesis.*
- *Quantify your observations wherever possible.*
- *Test the entire argument -- "If there's a chain of argument,* every *link in the chain must work (including the premise)--not just most of them".*
- *Use Occam's Razor -- when two or more hypotheses explain the data equally well, choose the simplest hypothesis.*
- *"Always ask whether the hypothesis can be, at*

least in principle, falsified. Propositions that are untestable, unfalsifiable are not worth much ... You must be able to check assertions out. Inveterate skeptics must be given the chance to follow your reasoning, to duplicate your experiments and see if they get the same result."

A useful guide in conducting scientific research is the National Academy of Sciences publication *On Being a Scientist.*[35]

Lessons Learned

In the concluding chapter of his book, *Cold Fusion: The Scientific Fiasco of the Century*, Professor John R. Huizenga lists 15 lessons from which we all may profit in conducting research. These lessons are [13]

- **Handling far-out ideas and claims**

Far-out ideas and claims should be presented first informally at a meeting of colleagues to address the hard questions. Where the work involves science or technology outside the advocate's main area of expertise the briefings should include experts from those areas. When all questions have been answered and all the experimental checks made one should present the results to other experts outside the laboratory or organization and then submit to the peer-review process.

- **Judging hypotheses**

One should avoid the extreme position of rejecting all previous work in the field just because one has obtained some anomalous result. If a hypothesis requires the belief in several miraculous occurrences then the hypothesis is probably pathological.

- **Premature publication**

Researchers should submit to the full peer review process to avoid being caught later with an unsound paper. Editors and reviewers also have a responsibility to ensure the technical soundness of a paper. Where there is some justifiable need for urgent publication the editor can always put a disclaimer on the paper noting that it has not been peer reviewed. (The author proposed something like this for speculative papers submitted to the annual Intersociety Energy Conversion Conference not only as a caution for other researchers but as a warning to potential investors.)

- **Publication by press conference**

The announcement of a new scientific discovery at a press conference should only be done where it is justified and where there is enough supporting information to back up the claimed discovery. Generally, it is far better and safer to "announce" the discovery through the normal peer review process.

- **Publication of primary data**

Researchers should publish enough of their primary data and experimental procedures to enable other researchers to check their results. If mistakes are later found these should be formally noted in the same publication that carried the original data.

- **Reproducibility in science**

Researchers should publish sufficient information about how they conducted their experiments so that other researchers can check their work. As Huizenga has written, "The foundation of science requires that experimental results must be reproducible. Validation is an integral part of the scientific process".[13]

- **Scientific isolation in research**

Breakthroughs in science generally are made by researchers who are fully knowledgeable in their fields and in contact with other researchers. In contrast, University of Utah officials claimed that the isolation of Pons and Fleischmann from both the traditional centers of fusion research and from nuclear scientists was what led them to make their claimed breakthrough discovery of cold fusion. Unfortunately, when their cold fusion results could not be duplicated by reputable, objective (and skeptical) scientists, cold fusion was dubbed another example of the "Utah Effect" (a term first used in connection with University of Utah Professor Edward Eyring's 1972 mistaken claim of discovering the x-ray laser).[13,14]

- **Control of information**

Researchers must be open with and willing to share their research data and experimental techniques. Free and open communication is central to the scientific process.

- **Secrecy in basic research**

Basic research is best conducted openly with the peer review process. If the research is done in secret the kinds of errors that afflicted so-called cold fusion can occur. Similar problems occurred when the former Strategic Defense Initiative Organization (SDIO) tried to develop a nuclear rocket code-named "Timber Wind" using a technology (particle bed reactor) that was highly questioned by outside experts. In that case people who had technical concerns about the viability of the concept were either ignored or denied further access to information on the program.[36]

- **Discovery by outsiders**

There seems to be a growing belief that only people who are not experts can make breakthrough discoveries because their minds are not clouded by "official" science. The facts are quite different--it is very rare that a non-expert makes a breakthrough discovery outside his or her field. As Prof. Huizenga has observed, "Most fundamental discoveries are made by persons intimately familiar with their research discipline because they not only know the subject matter of the field but also know the pitfalls and traps and have made many of the obvious mistakes".[13]

- **Lobbying before Congressional committees**

Lobbying before Congressional committees is contrary to the scientific process of peer review and it is particularly dangerous when the advocates are championing something like cold fusion which has not been confirmed. Not only is lobbying for unproven concepts damaging to science it wastes the country's limited research funds. Prof. Huizenga has estimated that "It has taken upwards of some fifty to one hundred million dollars of research time and resources to show that there is no convincing evidence for room temperature fusion".[13] Timber Wind cost the U.S. at least $139 million between Government Fiscal Years 1987 and 1991 largely on the basis of Congressional lobbying.[36] Thermionic reactor research has cost the country on the order of $500 million in today's dollars.[19] These monies could have been better spent on peer-reviewed space technology of more benefit to the country.

- **Funding large initiatives**

Large initiatives should be funded only when there is clear, objective, peer-reviewed evidence in support of the concept.

- **Patents and revenues from basic science**

If the concern is over protecting patent and intellectual property rights, the normal process is to verify the scientific results first, then file the patents and then announce the work. The process of announcing the results first with very limited information and no scientific verification was a key contributor to the cold fusion fiasco.

- **The press and basic science**

The press should explore claims of breakthrough science thoroughly making sure that the public is being given a true picture of what is claimed. The preferred process for publicly reporting new discoveries is to wait until the research paper has been peer reviewed and accepted for publication by a respected journal in the field. Using press conferences before complete scientific papers were accepted contributed to the confusion about and eventually distrust of claims of cold fusion.

- **The scientific process**

Claims of breakthrough discoveries should be made through the usual scientific process of peer review and validation through independent reproduction of the results.

Concluding Remarks

Advanced propulsion research must be continued because of the tremendous payoff it offers to our ability to conduct scientific, exploration, and commercial space missions. However, in our studies of advanced propulsion concepts we should be guided by the scientific method so that we can avoid the types of pitfalls that have ensnared other scientists in what Irving Langmuir has called "pathological science". Physicist Richard P. Feynman said it best in his minority report on the Challenger accident: "For a successful technology, reality must take precedence over public relations, for nature cannot be fooled".[37] Unfortunately, what has often occurred with pseudoscience is that "... for the survival of an unsuccessful technology, public relations must take precedence over reality".[14] If we ignore reality then everyone loses and our research field is damaged.

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An Experimental Investigation of the Physical Effects in a Dynamic Magnetic System

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AN EXPERIMENTAL INVESTIGATION OF THE PHYSICAL EFFECTS IN A DYNAMIC MAGNETIC SYSTEM.

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Abstract

In the current paper the results of experimental research of magnetic-gravity effects are presented. Anomalous magnetic and thermal changes within a radius of 15 meters from the researched device were measured as well.
PACS: 41.20.-q; 44.60.+k; 76.50.+q

Introduction

We have experimentally studied the physical effects in a system based on rotating permanent magnets [1]. Below we describe the technology of manufacture, assembly, and the results of testing this experimental setup, which is referred to as the converter.

Received effects:

- Generation of mechanical energy in a self-governing mode of operations;
- Change of weight of the converter;
- Formation of a local magnetic and temperature fields as concentric cylinders around converter.

Description of the Experimental Setup

The basic difficulty arises in choosing the materials and maintaining the necessary magnetic pattern ("imprinting") on the plate and roller surfaces. To simplify the technology we decided to use a one-ring design with one-ring plate (stator) and one set of rollers (rotor). It is obvious, that it was necessary to strengthen the rollers on a rotor by the bearings and balance the rollers well. In the suggested design, air bearings were used which provided the minimum losses due to friction.

From the available description [1] it was not clear how it is possible to make and magnetize the stator with a diameter of about one meter. In order to make the stator from separate magnetized segments executed with rare earth magnets with the residual induction of 1T, the segments were magnetized in a usual way by discharging a capacitor-battery energizer through a coil. Afterwards the segments were assembled and glued together in a special iron armature, which reduced magnetic energy.

To manufacture the stator 110 kg of rare earth magnets were used. To manufacture the rotor 115 kg of that material was used. High-frequency field magnetization was not applied. It was decided to replace imprinting technology described in [1] with cross-magnetic inserts having a flux vector directed at 90 degrees to the primary magnetization vector of the stator and rollers. For these cross-inserts the modified rare earth magnets with residual magnetization of 1.2 T and coercive force a little bit greater than in a base material were used. Fig.1 and Fig.2 show the joint arrangement of stator 1 and rotor, made up of rollers 2, and a way of their mutual gearing or sprocketing by means of cross magnetic inserts 19. Between the stator and roller surfaces air gap δ of 1 mm is maintained.

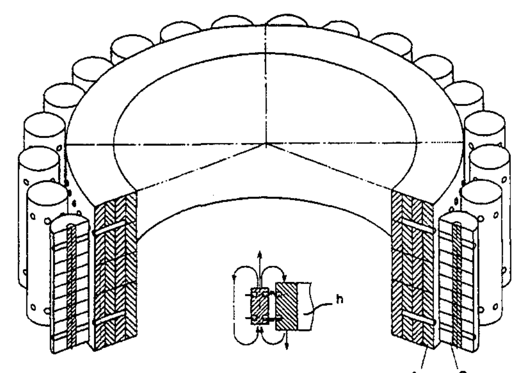

Fig. 1. Variant of one-ring converter.

No layered structure was used except a continuous copper foil of 0.8 mm thickness, in which the stator and rollers was wrapped up. This foil had a direct electrical contact to magnets of the stator and rollers. Distance between the inserts in rollers is equal to distance between the inserts on the stator. In other words $t_1 = t_2$ on a Fig.2.

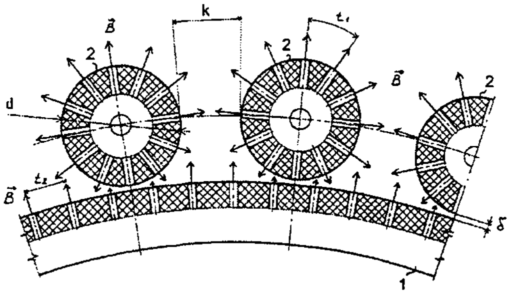

Fig.2. Sprocket effect of magnetic stator and roller inserts.

The ratio of parameters of the stator 1 and the rotor 2 on Fig.2 is chosen so that the relation of stator diameter D to the roller diameter d is an integer equal to or greater than 12. Choosing such ratio allowed us to achieve a resonant mode between elements of a working body of the device.

The elements of magnetic system were assembled in a uniform design on an aluminum platform. Fig.3 displays the general view of the platform with the one-ring converter. This platform was supplied with springs, shock absorbers and had a possibility of moving vertically on three supports. The possible vertical displacement was 10mm and the induction meter 14 was used for measuring this displacement. Thus, the instantaneous change of platform weight was defined during the experiment in real time. Gross weight of the platform with magnetic system in an initial condition was 350 kg.

The stator 1 was mounted motionlessly and the rollers 2 were assembled on a mobile common rotor - separator 3, which is connected with the basic shaft 4 of the converter. Through this shaft the rotary moment was transferred. The basic shaft by the means of friction muff 5 was connected to a starting engine 6, which accelerated rotor of the converter up to a mode of self-sustained rotation. An ordinary DC electrodynamics generator 7 also was connected to the basic shaft as a main loading of the converter. Adjacent to the rotor, electromagnetic inductors 8 with open cores 9 were located.

The magnetic rollers 2 crossed the open cores of inductors and closed the magnetic flux circuit through electromagnetic inductors 8, inducing an electromotive force in them, which acted directly on an auxiliary active load 10 - a set of incandescent lamps with total active power of 1 kW. The electromagnetic inductors 8 were equipped with an electrical drive 11 on supports 12. Driven coils were used for smooth stabilization of the rotor rpm. The speed of the rotor also could be adjusted by changing the main loading 10.

To study influence of high voltage on characteristics of the converter, a system for radial electrical polarization was mounted. On a periphery of rotor the ring electrodes 13 were set between the electromagnetic inductors 8 and had an air gap of 10 mm with the rollers 2. The electrodes are connected to a high-voltage source; the positive potential was connected to the stator, and the negative - to the polarization electrodes. The polarizing voltage was adjusted in a range of 0-20 kV. In the experiments, a constant value of 20 kV was used.

In case of emergency braking, a friction disk from the ordinary car braking system was mounted on a basic shaft of the rotor. The electrodynamics generator 7 was connected to an ordinary passive resistive load through a set of switches guaranteeing a step connection to the load from 1 kW to 10 kW - a set of ten ordinary electric water heaters.

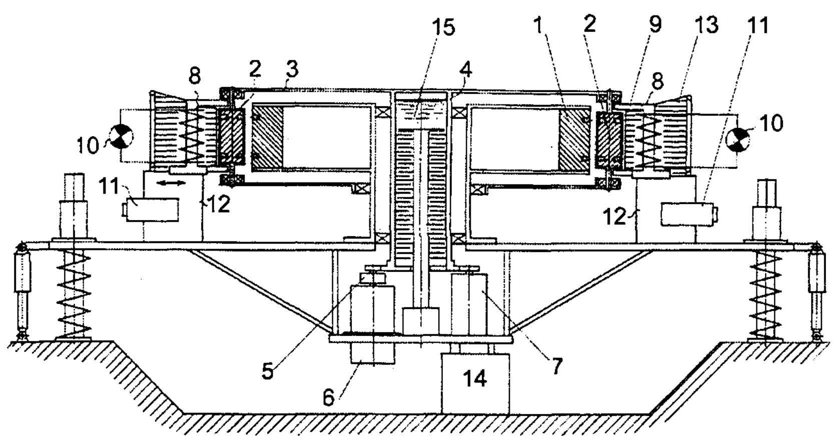

Fig.3. The general view of the converter and its platform.

Converter under testing had in its inner core the oil friction generator of thermal energy 15 intended for directing a superfluous power (more than 10 kW) into the thermo-exchange contour. But since the real output power of the converter in experiment has not exceeded 7 kW, the oil friction thermal generator was not used.

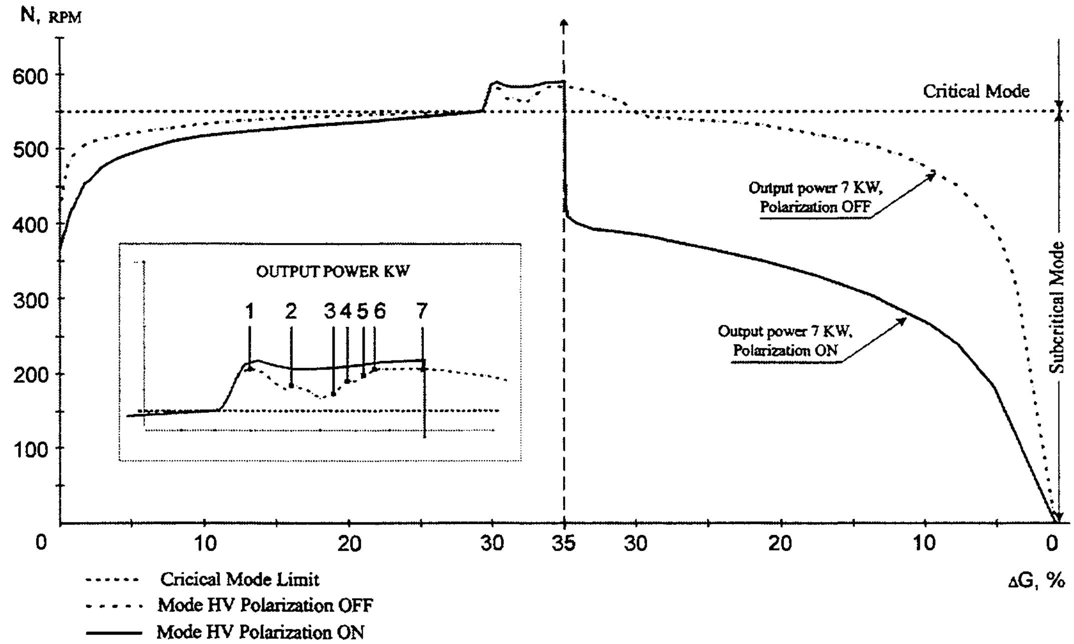

Fig.4. A diagram illustrating various operation regimes of the converter, -G, +G changes in weight of the platform vs. rpm

Experimental results

The magnetic converter was mounted in a laboratory room on three concrete supports at a ground level. The ceiling height of lab room was 3 meter. A common working area of the laboratory was about 100 sq. meters. Besides a presence of an iron-concrete ceiling in the immediate proximity from the magnetic system there was a generator and electric motor, which contained tens of kilos of iron and could potentially deform the field structures.

The device was started by the electric motor, which accelerated rpm of the rotor. The revolutions were smoothly increased up to the moment the ammeter included in a circuit of the electric motor begin to show zero or a negative value of consumed current. The negative value indicated a presence of back current. This back current was detected at approximately 550 rpm under clockwise rotation. The displacement meter 14 starts to detect the change in weight of the whole installation at 200 rpm. Afterwards, the electric motor is completely disconnected by the electromagnetic muff and an ordinary electrodynamics generator is connected to the switchable 10 kW resistive load. The converter rotor continues self-accelerating and approaches the critical regime of 550 rpm when the weight of the whole installation quickly changes.

In addition to dependence on a speed of rotation, the common weight of device depends from output power on the load and from applied polarizing voltage as well. As seen on Fig.4, under maximum output power is equal to 6-7 kW the change of weight ΔG of the whole platform (total weight is about 350 kg), reaches 35 % of the weight in an initial condition G_i. Applying a load of more than 7 kW results in a gradual decrease of rotation speed and an exit from self-sustained mode (right sides of the curves on Fig.4 for a 7 kW loading).

The net weight G_n of the platform can be controlled by applying high voltage to polarization ring electrodes located at a distance of 10 mm from external surfaces of the rollers. Under a high 20 kV voltage (electrodes have a negative polarity) the increase of tapped power of the basic generator more than 6 kW does not influence ΔG if rotation speed is kept above 400 rpm. "Tightening" of this effect is observed as well as the effect of hysteresis on ΔG at rotation of a rotor on a clockwise and counter-clockwise (a kind of "residual induction"). The experimental diagrams given on Fig.4 illustrate the +G and –G changes in weight of the converter vs. rotor rpm. The effect of a local change of the platform weight is reversible, relative to the direction of rotor revolution, and has the same hysteresis. A clockwise rotation causes the critical regime to occur in area of 550 rpm and a propulsion force against the direction of gravitation vector is created. Correspondingly, a counter-clockwise rotation causes the critical mode to occur the in area of 600 rpm and a force in the direction of gravitation vector is created.

The difference in approach to a critical regime of 50 - 60 rpm was observed. It is necessary to mention that the most interesting region are situated above the critical area of 550 rpm, but due to of a number of circumstances the implementation of such research was not possible. Probably, there are also other resonant modes appropriate to higher rpm of a rotor and to the significant levels of useful loading and weight changing. Proceeding from the theoretical assumptions, the dependence of tapped mechanical energy from the parameters of magnetic system of the converter and rpm of a rotor has a non-linear character and the received effects are not optimum. From this point of view, the revealing of a maximal output power, of maximal change of weight and converter resource represents a large practical and scientific interest. In tested sample of the converter the using of higher rpm was inadmissible because of unsufficient mechanical durability of the magnetic system, which has been stuck together from separate pieces.

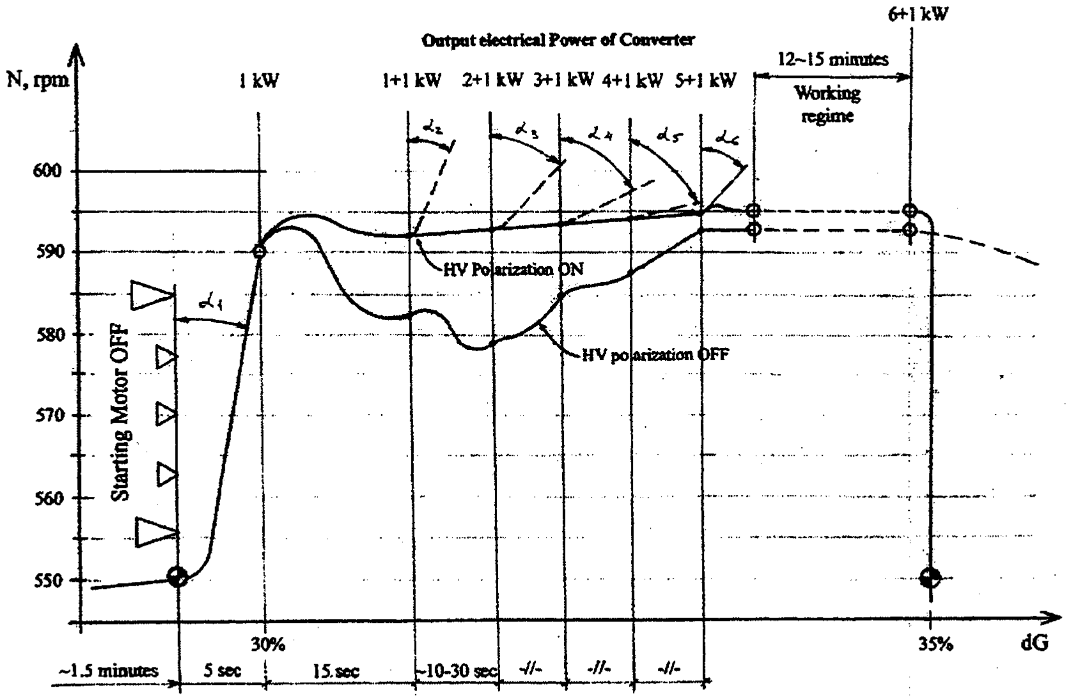

Fig.5 Diagrams of rotor accelerating and loading of the converter.

On Fig.5 the dependence of total weight of whole installation and its output power directed into active loading from rpm of a rotor of the converter is explained in detail. The diagrams are constructed for a case of HV polarization ON (top diagram) and HV polarization OFF (bottom diagram). The time from starting of the engine up to a mode of self-sustaining of the converter at the rotation of a rotor clockwise approximately is equal 1.5 minutes. Power of starting DC engine was about of 2 kW and reduction on a shaft of the converter was equal 1/10. At achievement of a critical mode (550 rpm.) the change of gross weight of a platform already achieves +/-30% from G_i. Under transition to resonant mode the revolutions with the large acceleration have increases up to 590 rpm and weight has changes up to + /-35% from G_i. This point on the diagram begins at once after a critical point (inclination of a curve α_1). At achievement of 590 rpm the first stage of active loading 1 kW is connected to the electrodynamics generator. The revolutions have a sharply reducing and ΔG also is changing. As soon as the revolutions begin to grow again, the second switchable loading is connected and rotor rpm are stabilized at a level of 590-595 rpm. ΔG continues to change. The increasing of switchable loading occurs by steps on 1 kW up to total power of 6 kW. All intervals are equal approximately of 10-30 sec. Afterwards the short-term increasing of revolutions and then the full stabilization of the 6 kW output during of 12-15 min was observed.

More than 50 launches of the converter with an absolute repeatability within three months were carried out. It is necessary to note that revolutions will grow with acceleration shown on Fig.5 by angles $\alpha_1 \ldots \alpha_5$, if do not switch on the next step of loading to the generator at rpm increasing. For returning to a previous rpm mode it is necessary to switch on a twice more loading.

The words above concern a mode with switched ON a high voltage polarization of 20 kV, "plus" is on a grounded stator. Without polarization voltage (lower curve on Fig.5) the diagram is approximately the same, but is well indicated the more soft character of a loading and faster changing of weight of a platform due to decreasing of rpm.

Other interesting effect is corona discharges, which was observed at the work of the converter in a dark room. At this, around the converter rotor a blue-pink glowing luminescence and a characteristic ozone smell were noticed. On Fig.6 the cloud of ionization covers area of the stator and rotor and is having accordingly a toroidal form.

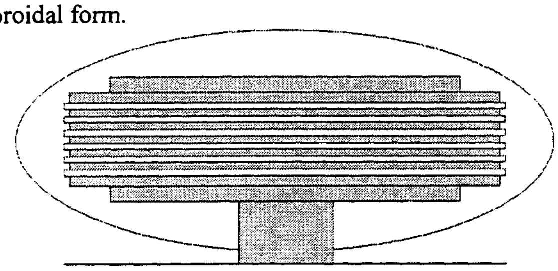

Fig.6. Corona discharges around the converter.

On a background of luminescence glowing on the roller surfaces, we distinguished a separate «wave picture». A number of more vigorous strips of discharges around the rollers were observed. These discharges were of a white-yellow color but the characteristic sound for arc discharges was not audible. There were not noticed any erosive damages by arc discharges on surfaces of the stator and the rollers as well.

One more effect previously not mentioned anywhere was observed - the vertical concentric magnetic "walls" around the installation. We noticed and measured a permanent magnetic field around the converter within a radius of 15 meters. For this magnetic field measurement a Russian made magnetometer F4354/1 was used. Magnetometer had a Hall-effect sensor in a copper shielding. The zones of increased intensity of a magnetic flux 0.05 T, located concentrically from the center of the installation were detected. The direction of the magnetic field vector in these walls coincided with direction of magnetic field vector of rollers. The structure of these zones was like the Bessel function of zero order of two arguments. No any magnetic fields were registered between these zones by portable magnetometer. The layers of increased intensity were distributed practically without losses up to a distance of about 15 meters from a center of the converter and had a quick decreasing at a border of this zone. The thickness of each layer was approximately of 5 - 6 cm the border of each layer was very sharp. The distance between layers was about of 50 - 80 cm where the upper value is seen when moving from center of the converter. A stable picture of this field was observed as well as at a height of 6 m above the installation (on the second floor above the lab). Above the second floor, measurements were not carried out. The similar picture was observed and outside of a room of laboratory, directly in the street, on the ground. The concentric walls were strictly vertical and no had appreciable distortions. The Fig.7 illustrates the schematic placing of the converter in a room of laboratory and arrangement of concentric magnetic and thermal fields around the installation.

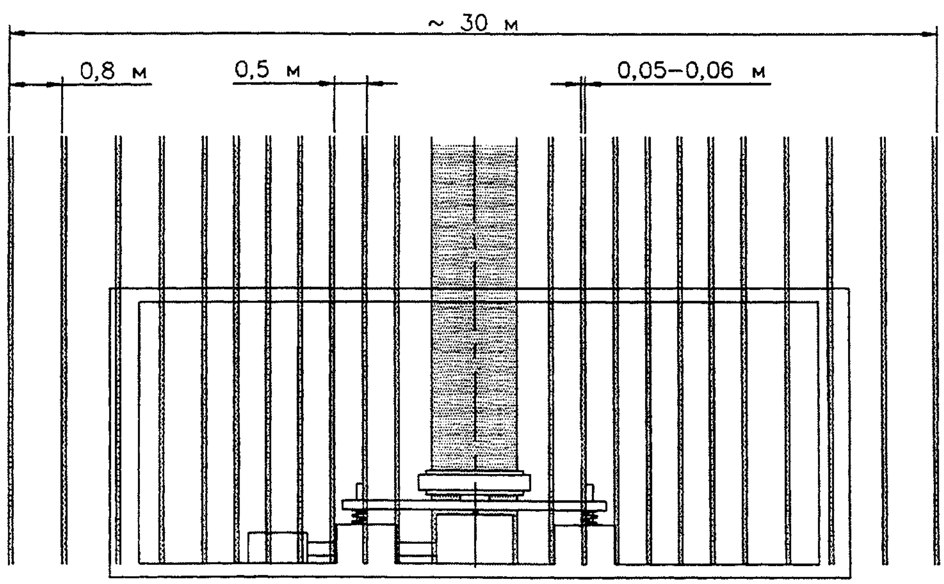

Fig.7. Schematic placing of the converter and field patterns in lab room.

An anomalous decrease of temperature in a vicinity of the converter was also found. While the common temperature background in laboratory was + 22°C (±2°C) the stable fall of temperature of 6-8°C was noticed. The same phenomenon was observed in concentric vertical magnetic walls as well as. The measurements of temperature inside the magnetic walls were carried out by an ordinary alcohol thermometer with an inertia of indication about 1.5 min. Inside the magnetic walls the temperature changes can even be distinctly observed by hand. When the hand is placed into this magnetic wall the cold is felt at once. A similar thermal picture was observed at height above the installation, i.e. on a second floor of the laboratory as well as despite the steel-reinforced concrete blocks of a ceiling and also on an open air outside of the laboratory.

Concentric magnetic walls and accompanied thermal effects begin to appear approximately from 200 rpm and have a linearly increasing with speeding up of revolutions up to a critical regime. The measurements above 600 rpm were not made because of fear of destruction of magnetic system. On Fig.8 the curve of intensity of magnetic field in mT and change of temperature in Celsius degrees due to rpm changing is represented.

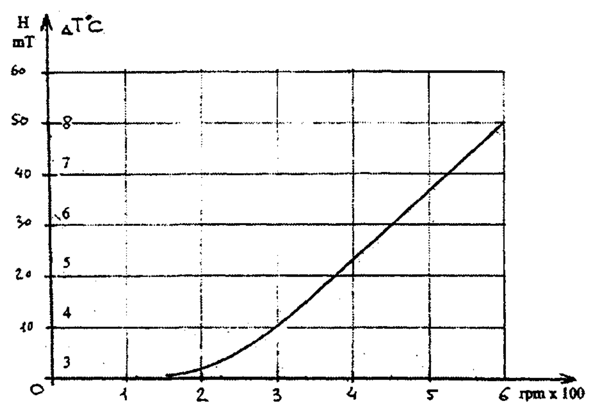

Fig.8. The dependence of intensity of magnetic field and changes of temperature vs. rotor rpm of the converter.

Discussion

All the results we obtained are extremely unusual and require some theoretical explanation. Some theoretical approaches and phenomenological descriptions can be found in our book [2]. Unfortunately, interpretation of these results within the framework of conventional physical theory cannot explain all observed phenomena especially the change of weight. We can interpret change of weight as a local change of gravitation or as some propulsion force like a propeller work in air. Only a role of a propeller the magnetic system is playing, and a role of air - the quantum environment - ether filled with a "dark matter and energy". Direct experiment, which would has confirming the presence of a propulsion force was not performed, but in any case both interpretations of the weight change do not correspond to the modern physics paradigm.

In conclusion we would like to emphasize that issues of biological influence and especially effects of unknown radiation around of the converter were not considered at all. Our own experience allows us to do only cautious assumption that the short-term stay (dozen minutes) in a working zone of the converter with fixed output power of 6 kW remains without observed consequences for exposed persons.

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A IAA 2001-3364

EXPLORATION OF ANOMALOUS GRAVITY EFFECTS BY MAGNETIZED HIGH-T_C SUPERCONDUCTING OXIDES

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ABSTRACT

Driven by the knowledge that mass-ejection from a rocket engine is a major drawback in the exploration of space, investigations of fringe effects (or abnormalities) in known science and dealing with mass reduction was undertaken. This research, then examines the possible connection between gravity and electro-magnetic affects on the Type II, YBCO superconductor, as reported by the Russian scientist, Eugene Podkletnov. It is suggested that the quantum fluctuations of the electrons across the multitude of superconductor grain boundaries in a properly prepared Type II; superconductors may produce a measurable force on the vacuum that could counteract the effect of gravity, an acceleratory force. Within known physicists, the driving phenomena appears to relate to both the Maxwell Stress Tensor as derived by Oliver Heaviside and Woodward's transient mass theory. As a means of improving this understanding, a simplified laboratory experiment has been constructed using a modified–automated commercial Cavendish balance. The larger lead masses used in this balance was replaced by a system to EM modulate a superconductor. Tests results were inconclusive because at both room temperature and at liquid nitrogen temperatures the application of the electromagnetic (EM) or rf energy resulted in an upward climb in the data.

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INTRODUCTION

Engineers working in the aerospace fields dealing with rocket engine technology quickly learn that mass-ejection is a major drawback in the exploration of space. Using current rocket technology a trip to the next star would easy consume the mass-energy equivalent of a planet in order to arrive within a reasonable lifetime with reasonable hardware and expendables for the journey. Technologies like nuclear fission and fusion offer some hope, but still will not support the "Star Trek" vision of space exploration. Therefore, the NASA Propulsion Research Center at the Marshall Space Flight Center in response to the propulsion challenges specified by the NASA Breakthrough Propulsion Physics (BPP)** project, specially to investigations fringe effects or abnormalities in known science and dealing with mass reduction, proposed to explore the recently report observation of anomalous gravitation behavior in experiments using high temperature superconductor.

The thesis of this research is to see if there is a possibility to circumvent the rocket equation without violating physical laws and to produce valid experimental data that can be used to show credible validation of these effects. The intend here is then to examining the possible connection between gravity and electro-magnetic affects on the Type II, YBCO superconductor, as reported by the Russian scientist, Eugene Podkletnov and provide a rigorous, independent, empirical conformation (or refutation) of the effect.

It has been suggested that the quantum fluctuations (or electromagnetic nature) of the electrons across the multitude of small

** Lead by the NASA Glen Research Center superconductor grains, called Josephson junctions, in properly prepared sintered Type II, superconductors may produce a measurable force on the vacuum (i.e., space vacuum) that could counteract the acceleratory force of gravity.

The experiment that was proposed utilizes a commercially available torsion balance called a Cavendish balance, which is commonly used by physics students to measure the value of the gravitational constant. The extent of the experiment is not to measure the gravitational constant, but to measure the change in the dynamic angle induced on a torsion beam as a result of the attraction between the beam masses and external test masses (i.e., superconductor). In theory, the values of the calculated dynamic angles between two tests should be different if the masses are of different weight values. Assuming that the characteristics of the balance do not change between tests, the difference between the two dynamic angles can be used to correlate the mass change. Whereby, if a change is detected between a superconductor and an electro-magnetically radiated superconductor, one can deduce that there is a possibility that an interaction with the vacuum had occurred.

The research conducted here is but a first step in the possible application of a theory into an applicable engineering space drive model, which can then be used to design a purely massless propulsion system for interplanetary applications.

A successful or null test would however, not indicate the full benefit of the phenomena nor that it is truly a physical effect. Whereby, further testing would need to be conducted to validate the results and to devise the true nature and applicability to a space propulsion system.

BACKGROUND

A number of anomalous gravitational effects (or acceleratory forces) have been reported in the scientific literature during recent years, but there has been no independent confirmation with regard to any of these claims. One such experiments was reported by the Russian scientist, Eugene Podkletnov, in which he reported anomalous weight loss (0.05–2.1%) for a variety of test masses suspended above a rotating YBCO[#], type-II superconductor.[1,2] Further experiments using simplified apparatus without rotation have reported transients of up to 5% weight loss.[3,4] Still, a great deal of skepticism continues to be expressed, mainly due to uncertainties associated with experimental technique. Other researchers, for example, have yet to duplicate Podkletnov's rotating disk experiments and obtained null results in a set of simplified experiments using a stationary disk.[5]

The technical goal was then to critically test this revolutionary physical claim and provide a rigorous, independent, empirical confirmation (or refutation) of anomalous effects related to the manipulation of gravity by rf-pumped magnetized type-II superconductors. Because the current empirical evidence for gravity modification is anecdotal, our objective was to design, construct, and meticulously implement a discriminating experiment, which would put these observations on a more firm footing within the scientific community. Our approach is unique in that we advocate the construction of an extremely sensitive torsion balance with which to measure gravity modification effects by rf-pumped type-II superconductor test masses.

Three competing theoretical explanations have been proposed to explain these gravitational anomalies: (1) gravity shielding,[1,2] (2) absorption via coupling to a Bose condensate,[3,4] and (3) a gravito-magnetic force.[5-9, 18] To date, however, there has been no definitive corroboration between any of these theories and empirical observations. Therefore, it is clear that carefully designed and meticulously executed experiments are needed to explore these anomalies and to convincingly demonstrate the alleged effects. However, validation of a new theory is in itself a long and mischievous task. This is more so when you have to consider the nature of electrons at the atomic scale.

In light of the granular nature of a sintered YBCO superconductor disk, one can address the much larger grain interfaces in more macroscopic terms using electric-potentials, displacement currents, and magnetic fields. This is due to the Josephson junction effect at the interface, which is somewhat like an AC capacitor.

A search of the literature has produced several experiments using capacitors to interact with the vacuum to cause a force; 1) the Trouton and Noble (T-N) experiment[21], 2) the Biefield-Brown (B-B) experiment[10], 3) the Graham and Lahoz (Heaviside) experiment[20], and 4) the Woodward (Transient Mass) experiment[17].

ENGINEERING APPLICATION OF QUANTUM VACUUM

[#] Yttrium, Barium, Copper, and Oxygen.

As aerospace engineers we deal more with the technology development of machines that have proven to work within the physical boundaries of known physical laws, which govern the rocket equations. Speculative theories can only lead to misunderstanding and lost paths. Therefore, space propulsive systems are designed to overcome gravitational forces by the application of time varying the mass of a vehicle, i.e., the exhausting of onboard mass at high velocities. What seems to be lost in this rational is that as the propellant becomes smaller with higher and higher exhaust velocities, as in the case of a laser or photon drive, the mass approaches a more quantum state. The logical next step would then be to connect propulsion to the quantum vacuum through acceleratory forces, i.e., gravity.

Long ago internationally renowned physicists hypothesized that gravity is an induced effect associated with zero point fluctuations (ZPF) of the quantum vacuum.[13-14] Zeldovich first suggested that gravitational interactions could lead to a small disturbance in the non-zero quantum fluctuations of the vacuum and thus give rise to a finite value of Einstein's cosmological constant.[13] Sakharov later derived a value for Newton's gravitational constant G using frequency w as the only free parameter.[14]

$$G = c^5/h\int w\,dw \tag{1}$$

where c is the speed of light and h is the Plank constant. The integral is carried out over all frequencies using the Plank frequency on observable electromagnetic phenomena (w_p ~ 10^{-33} cm) as a cutoff value.

Using this hypothesis as a basis, Puthoff has further extended Sakharov's condition in a relativistically consistent manner.[15] As a result of this work, it is possible to envision the attractive force of gravity in terms of the radiative interaction between oscillating charges. That is, the zero point field applied to subatomic particles. From this standpoint, it is plausible that MHz frequency irradiation of superconductors rich in Josephson junction sites, as occurred in Podkletnov's experiments, could lead to a gravity modification effect through quantum ZPF interaction.

Scientific evidence continues to mount in favor of a frequency dependent interpretation of gravity as an induced effect associated with the zero point fluctuations of the vacuum. Accelerating theoretical progress combined with the anomalous gravity modification effects observed in experiments with irradiated Type II superconductors leads one to strongly suspect a deep physical connection.

THE PODKLETNOV EXPERIMENTS

Podkletnov's gravity modification experiments were conducted in the early 1990's. Nevertheless, skepticism persists, especially since the experiments have not been adequately documented and repeated. Podkletnov reports the use of fairly large superconductor disks, 10 and 12 inches in diameter and approximately ½ inches thick, which were magnetically levitated and magnetically rotated in the presence of an rf electromagnetic field. Samples placed over the rotating disk initially demonstrated a weight loss of 0.2─0.5%. When the rotation speed was slowly reduced, the shielding effect became considerably higher and reached a maximum reduction of 1.9─2.1%.

Of what is known of the YBCO superconductor disk used in these experiments, it seems certain that a large number of superconductor-oxide Josephson junctions exist within the disk. These types of Josephson junctions, when conversed by an ac current, emit electromagnetic waves in the rf frequency range, and when radiated at rf frequencies, generate an ac current. In a general sense, Josephson junctions are very small capacitors with the electrodes composed of superconductor material and the dielectric composed of an oxide layer.[12] The junction is modeled as shown in figure 1, where the superconductors (SC) are small sintered grains (noting that one or both of the grains could be a normal conductor), rf is the rf energy applied, JJ is the Josephson junction site, and i is the induced or applied current.

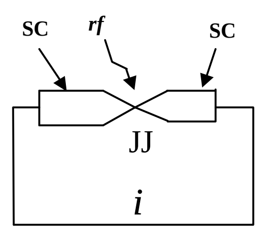


Figure 1. SC Josephson Junction Model.

A superconductor with a structure of sintered grains would have many flux pinning sites around which Josephson junction sites exist. Flux pinning is a well-known phenomenon associated with type-II superconductors (like YBCO) where magnetic flux penetrates the superconductor and is held in place by self-generated super-currents. Flux pinning results from any spatial inhomogeneity of the material, such as impurities, grain boundaries, voids, etc. where the magnetic flux can become trapped. To be most effective, these inhomogeneities must be on the scale of the order of the penetration depth or the coherence length, i.e. ~10.6 to 10.5 cm, rather than on the atomic scale where inhomogeneity causes electronic scattering which limits the mean free path.[12]

The Josephson junction sites at the grain boundaries would generally not produce flux pinning due to the resistive nature of the boundary. The exceptions might be under very high static magnetic field conditions. Radiation of the sites with rf energy would allow current flows, but could cause the flux to vibrate and jump from one site to another depending on the frequency.

Experiments conducted on both sintered and melt textured YBCO superconductors for the purpose of magnetic flux compression have shown that the rapidly moving flux with a millisecond rise time to approximately 1 kilogauss penetrates the superconductor with little (<35 gauss) compression of the field.[Ψ] This would indicate that a magnetic field could easily move through the body of a sintered superconductor to produce currents within the grain structure. Contradictory to this, it has also been shown during tests to repeat the Podkletnov experiment that an AC magnetic field will levitate a sintered (12 inch) disk.[++]

Podkletnov's experiment used both AC magnetic fields and rf energy. It would therefore seem that Podkletnov has produced a device to enhance the production of rf energy and rf energy to enhance the production of superconductor currents. These reinforcing phenomena should lead to high electron densities in the superconductor disk, focused at the Josephson junction sites and generated at the junction frequency.

It is then suggested here that the quantum fluctuations of the electrons across the multitude of Josephson junctions in properly prepared Type II, superconductors may produce a measurable force on the vacuum that could counteract the effect of gravity.

OTHER RELATED EXPERIMENTS

The capacitive like nature of the Josephson junction would make one wonder if other experiments have been conducted using capacitors to affect the vacuum. Research of the literature indicates that experiments using capacitors as a coupling mechanism to the quantum vacuum is not a new idea. In 1904, Trouton and Noble (T-N) reported that a mechanical force could be detected from a charged capacitor, which was free to rotate[21]. And in 1929, Townsend Brown reported translational motion using the now famous Biefield-Brown (B-B) effect, which utilizes capacitors with extremely high electrical potentials (>70 kV)[10]. To the author's knowledge, no one has report a successful duplication of the B-B experiment.[11] However in 1998, Cornille, Naudin, and Szames reported a successful duplication of the T-N experiment also using voltages near 70 kV.[22]

[Ψ] Conducted by the first two authors.

[++] This work is being conducted under a NASA SBIR Phase II.

Trying to connect these two experiments to Podkletnov's experiment is somewhat deceptive as only statically charged capacitors with no magnetic fields were used. One could speculate that the leakage current across the dielectric medium could occur at some (low) frequency associate with the atomic electron energy states. Also, stray magnetic fields could have been present; at the least, the magnetic field of the earth was. From a more physical sense, the time varying magnetic fields in the Podkletnov experiment would have created time varying high electrical potentials in the superconductor.

In more recent times, Graham and Lahoz (in 1980) reported the use of a coaxial capacitor to produce rotational motion from the vacuum by setting up a non-vanishing Poynting vector, as Maxwell and Poynting foresaw and predicted by Heaviside's[**] time variation of Maxwell's equations.[20] Further, Woodward has recently done some very interesting work with capacitors, both theoretically and experimentally to validate the notion of a transient mass effect.[17] These two experiments do have similarity to the Josephson junction and a further clarification follows.

Heaviside Force

Oliver Heaviside in 1886 obtained an express from the divergence of the Maxwell stress tensor, which is a vector with units of force density (N/m^3), and therefore implies momentum transfer. Corum names this the Heaviside force f_H and gives it in vector form as

[**] Referred to as the Heaviside Force by Corum[19].

$$f_H = \frac{\partial (DxB)}{\partial t}, \qquad (2)$$

where D is the electric displacement and B is the magnetic induction[19].

Corum goes on to present a space-drive that was first presented in an essay by Joseph Slepian in 1949. In the essay, Slepian models the space-drive by employing an rf source to drive two solenoids and a parallel-plate capacitor electrically wired in series. The rf energy was directed between the plates and perpendicular to the electric field of the plates. In this arrangement, the current passing through the coils must also cross the capacitor. This is shown in figure 2.

In the Slepian model, one may say that the current can only cross the capacitor in the presence of an rf field. This is the case for a superconductor Josephson junction. In fact, Slepian space-drive model is a crude approximation of a Josephson junction and is only a short stretch to the junction model of figure 1.

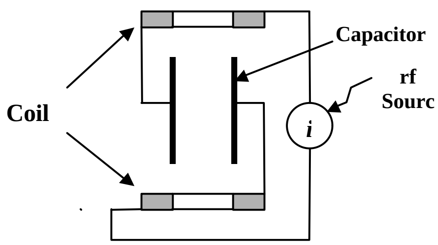


Figure 2. Slepian Space Drive Model.

Transient Mass Shifts

Woodward has come up with an equation for a transient mass shift (TMS) derived from Mach's Principle (Woodward, 1991). Woodward presented the transient mass shift ∂m_0 in general terms as:

$$\partial m_0 = \frac{b w P_0}{2 p G r_0 c^2}, \qquad (3)$$

where ∂m_0 is the transient mass; b is the ratio f/c^2 (f is the gravitational potential due to all the matter of the universe) and is approximately 1 and unitless; w is the frequency of the driving voltage into the capacitors in radians per second; P_0 is the power applied to the capacitors in Watts; G is the gravitational constant = 6.673 x 10-11 N m2/kg2; r_0 is the density of the capacitors; and c is the velocity of light = 2.9979 x 108 m/s.

A connection between Woodward's transient mass and Podkletnov's gravity modification experiment was presented in a previous paper.[16] In the paper, a model of the Josephson junction, transient mass relationship was given similar to figure 3.

As with figure 1, figure 3 presents a two-grain Josephson junction where one grain is a normal conductor NC and the other is superconductive SC. The current has been represented as a function $f(i)$ due to the uncertainty of this mechanism (i.e., time varying fields and rotation). The prospective is that electron charges e formed in the normal conductor. The application of the rf energy at the appropriate frequency allows the flow of electron to cross the junction as pairs $2e$. Noting the reverse effect is also possible.

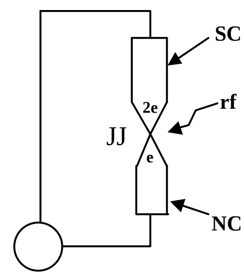


Figure 3. Josephson Junction TMS Model.

As cited in the previous paper, Woodward's TMS formula has commonality with Modanese's anomalous coupling theory (ACT)[3,4] and Woodward's capacitor experiment has commonality with the layered superconductor disk of Podkletnov's second experiment where the top part was a superconductor and the bottom portion a normal conductor. The TMS formula derives a mass fluctuation from a time-varying energy density. The ACT suggests that the essential ingredient for the gravity phenomenon is the presence of strong variations or fluctuations of the Cooper pair density (a time- varying energy density). Woodward's experiment used a small array of capacitors whose energy density was varied by an applied 11 kHz signal. When these are vibrated up and down at the correct frequency so that they are going up when their mass is minimum and going down when their mass is maximum, then a small, constant, mass-force change is possible. Podkletnov's superconductor disk contained many Josephson junctions, which were radiated with a 3-4 MHz signal. At the layered interface, the Cooper pairs are moving upward, while the electron pair separations are moving downward.

These commonalties allow for ease in rewriting superconductor mass shift ∂m as

$$\partial m_{sc} = \frac{b\, f_{jj} P_{jj}}{G\, r_{sc} c^2}, \tag{4}$$

where f_{jj} is the resonance frequency (in Hz) of the superconductor Josephson junctions, P_{jj} the effective combined power (in watts) of all the junctions, and r_{sc} is the density of the superconductor. Equation 4 then represents the mass change of the superconductor.

EXPERIMENTAL APPROACH

Repeating the original Podkletnov experiment has been a major undertaking within the Marshall Space Flight Center for several years. Confusion over the original experimental design and the ability to produce the large superconductors have been the major problems. Given these problems a much simpler experimental approach was devised to investigate the possible gravity connection. This approach has not been without problems.

The approach involved the replacement of the large (~1 kg) lead masses in a commercially available computerized torsion or Cavendish balance with a system that magnetically modulates an YBCO superconductor. A sketch of the proposed experiment is given in figure 4.

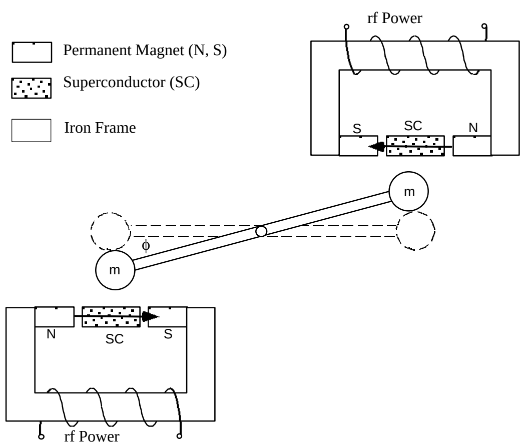


Figure 4. Sketch of the Cavendish balance experiment.

The measurement of the gravitation constant G (6.67×10^{-11} N·m^2/kg^2) using a Cavendish balance is a simple experiment, which is routinely performed by beginning physics students. Using Newton's universal law of gravitation, it is possible to express the angular displacement f of the beam in terms of directly measurable quantities

$$f = \frac{2GMml}{R^2 k} \tag{5}$$

where M is the test mass, m is the mass attached to each end of the beam, l is the separation length of the beam mounted masses, R is the distance from the center of each test mass to the center of each beam mounted mass, and k is the torsion constant of the fiber supporting the beam (not shown).

Corrections

The use of the Cavendish balance as supplied with the large lead masses requires several corrections. Such as a correction for the gravitational torque on the beam and the cross torque between the opposite masses. These corrections are easily approximated and are applied to the smaller masses. Other corrections such as the variations in R can be averaged out over many data points.

In this experiment, the spherical large lead masses are being replaced by a much larger mass that is more like a rectangular box. Such a shape makes the calculation of these corrections much more complicated without extensive testing. The simple solution is to look at the things that are measurable versus those that are not and see how these change from one condition to the other. Equation 5 is then rewritten as,

$$k_c\left(\frac{M}{R^2}\right) = \left(\frac{k}{2Gml}\right) f \tag{6}$$

where k_c is the correction to m the small mass.

Equation 6 can then be used in the formulation of a percent mass change $M\%$ even though the left side of the equation is unknown. For example, a percent mass change $M\%$ between a non-modulated superconductor mass M_1 and a modulated superconductor mass M_2 is just the ratio of the angular displacements f_1 and f_2, given by

$$M\% = \frac{M_2}{M_1} = \frac{f_2}{f_1} \tag{7}$$

where the angular displacements are measurable.

Sensitivity

Equation 6 also is true for two different tests using two different mass weights. The change in the measured angular displacement of the torsion fiber will then be directly proportional to the change in the test mass. For example, the change in angular displacement df associated with an effective change in the test masses dM is given by

$$\frac{df}{dM} = K_c G \tag{8}$$

The sensitivity of the device is therefore dependent on the magnitude of

$$K_c = \left(\frac{k_c}{R^2}\right)\frac{2ml}{k}. \tag{9}$$

By noting that the torsion constant $k = I(2p/T)^2$ where

$$K_c = \left(\frac{1}{R^2}\right)\left(\frac{2T^2}{lp^2}\right) \tag{10}$$

which is independent of the smaller mass and any correction to it as long as the period T is measurable.

Based on the published characteristics of the as delivered Cavendish balance a numerical estimate for the sensitivity was determined to be

$$\frac{df}{dM} = 0.3 \text{ microradians / gram} \tag{11}$$

for T = 120 sec, l = 30 cm, and R = 4.6 cm.

The commercially available Cavendish balance was chosen because it contained a computerized electronic detector known as a symmetric differential capacitive (SDC) control unit** to electronically measure the position of the beam as it rotates. The SDC is easily capable of measuring a displacement angle of 1 micro-radian. Therefore for a 0.5% weight change of a 300-gram superconductor, a displacement angle of 1.5 micro-radians would be detectable.

Testing has shown that the calculated displacement angle varies not with M but with M/R^2. This is due to the uneven mass density of the superconductor containment system or modulator that will be described later. That is, as the mass of the superconductor (or test mass) changes, the average density displacement of the modulator also changes, which in turn shifts the position of the modulators center of mass. This makes the determination of the percent mass change or equation 7 more difficult to determine. However, since we are only concerned at this point with seeing a change in the relationship between tests, the sensitivity to $1/R^2$ in equation 9 is a plus. In the general sense, the sensitivity as given in equation 11 is enhanced by the square of the difference in the shifted R values as a result of the test mass weight change.

Test Apparatus

In order to operate the balance in the hand-off operation inside a liquid nitrogen cyro-tank, the balance was fitted into a structure and the motion of the large masses was automated using a National Instruments, nuDrive (model 4SX-411) stepper motor controller and a National Instrument's rack (PXI-1010 Chassis) mounted computer (PXI-8156B) using Labview 5.1 software written specifically for this operation. The modified balance is shown in figure 5.

The large masses were replaced by a system, referred to as the modulator, which was required to modulate the superconductor sample with electromagnetic (EM) or rf energy. The modulator was composed of a superconductor, permanent magnets, an iron frame, a kHz coil, and an MHz antenna. Electrodes were placed adjacent to the superconductor to detect the hall current induced in the superconductor. A magnetic shield (1006 steel) was added due to an attraction problem with the balance's aluminum beam. A picture of the modified balance with the modulators is shown in figure 6 and a sketch of the modulator is shown in figure 7.

Figure 5. Automated Cavendish Balance.

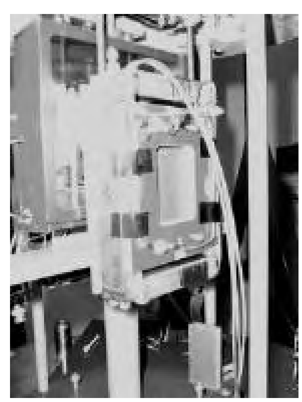


Figure 6. Modulator & Balance.

** The SDC is an invention of Dr. Randall Peters; Research Consultant.

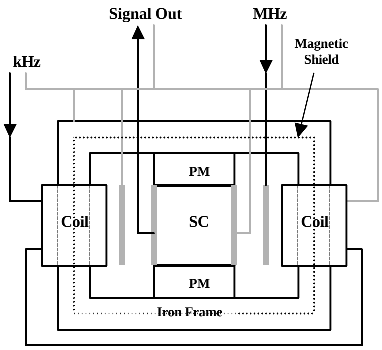


Figure 7. Sketch of Modulator.

The iron frame forms a magnetic circuit that directs the field through the superconductor and parallel to the balance's beam. The placement of the coil around the iron frame induces a time varying kHz field in the static field. The MHz antenna is placed near the coils also inducing a time varying field in the static field. The effect of these time varying fields were measured perpendicular to the static field.

The purpose of the static magnetic field produced by the permanent magnets was to induce currents in the superconductor about pinned flux sights and possibly the weaker holes about the grains, which would be much higher than that seen by the AC levitated superconductor in the Podkletnov experiment. The kHz modulation field would then act to break the pinning sites freeing the pinning currents to move according to the motion of the magnetic field in the superconductor material. In theory, the radiated MHz field reduces the resistance of the Josephson junction between the grain boundaries and to allow resistiveless passage of the currents throughout the superconductor.

The configuration of the superconductor then determines the mode of operation. That is, if the superconductor is composed entirely of sintered grains, the Heaviside force at the Josephson junction sights will dominate any gravity effect. On the other hand, if a non-superconducting, conductive layer is placed on the outward side of the sintered superconductor away from the balance; the electron motion across the boundary will produce a mass transit effect.

Instabilities

Several months were spent after the initial completion of the automated balance in determining and eliminating instabilities caused by the automation mechanism. The major mechanical problem was caused by the support apparatus, which would bend downward (ah gravity) as the modulator moved through the zero position. This allowed the spur gear to hit the support structure. Repositioning of the gear only made it hit other structures. The problem was fixed by grinding the top and bottom of the spur gear at an angle.

Placement of the drive motor also presented a problem. Due to the lack of support perpendicular to the balance beam, lead to the introduction of vibration. Placement of the motor such that the shaft rotation was in the plane of the modulator's motion and adding support structures provided a major reduction in the induced vibrations.

The deduction of these problems and the resulting fix thereof was hindered by the enclosure of the spur gear and the fact that some of the vibrations could only be detected by the analysis of the data. A data run was typically done overnight to allow the balance to stabilize. Three to five data cycles were typically required before stabilization occurred. One data cycle of about 35 minutes was required to get one dynamic angle measurement.

The only problem to arise during cooling in liquid nitrogen was with the electrical connections. Cooling below 170C caused intermittent signal disturbances. This was fixed by insulating the connections exposed to the liquid nitrogen temperatures.

TESTS RESULTS

Only one type of superconductor sample has been tested. It was composed of two layers; one of YBCO and one of PrBCO (Pr – Praseodymium). The substitution of Pr for Y was done to cause the layer to be a conductor with similar crystal structure to the YBCO. This sample was fabricated by the same manufacture producing the samples for the repeat of the Pokletnov experiment under a NASA SBIR phase II. Tests were conducted at room temperature and at liquid nitrogen (-196 C) temperature.

The YBCO superconductor only required < -180 C to become superconductive. The type K thermocouples used in the experiments flat lined between –186 C and –188 C in liquid nitrogen. Therefore to insure that the superconductor was in a superconductive state, tests were not conducted until a temperature < -186 C was optioned. The following graphs (figure 8 – 12) represent a data set using the same torsion wire. The numbers across the bottom (x

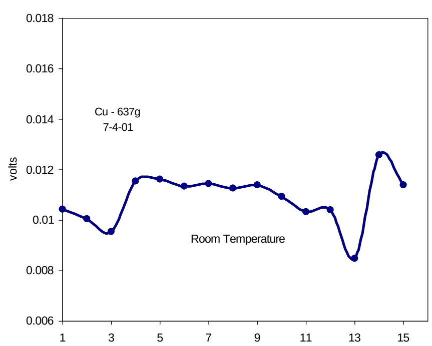
– axis) of each chart refers to the number of cycles from which each dynamic angle was calculated. The sequence is in order of time from start to finish of a data run. Each dynamic angle (or cycle) depended on the period of the torsion beam, but typically was between 30 and 40 minutes. The voltage value on the left (y -axis) of each chart refers to the calculated dynamic angle. The values have been left in its voltage value because the conversion factor for the control unit was stable between tests.

The results of the superconductor tests are base lined against a copper (Cu) sample.

<u>No-Modulation</u>

The results of the room temperature and the liquid nitrogen (i.e., superconductive) tests for the non-modulated or static magnetic field cases are shown in figure 8 and figure 9, respectfully.

As seen in the room temperature tests of figure 8, the calculated dynamic angles between the varying weighted masses increased with decrease mass weight due to the non-uniform density of the modulator (i.e., $1/R^2$). Additional tests were conducted using other weights composed of fiberglass epoxy, aluminum, and lead, which showed the same result.



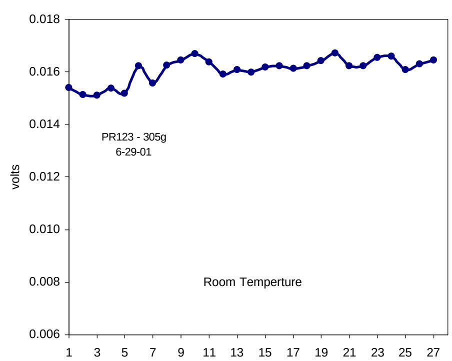


Figure 8: Dynamic Angle of copper sample (Cu) and superconductor sample (PR123) at room temperatures.

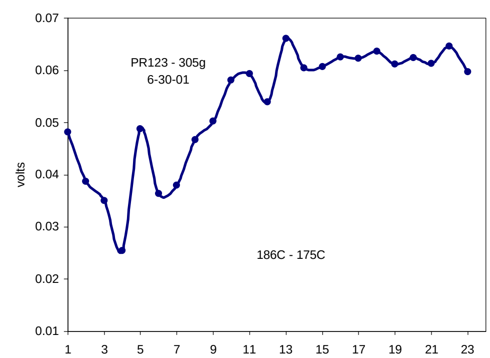
In the liquid nitrogen tests of figure 9, the tests were started when the superconductor was at superconductive temperatures and allow to warm-up over night. As shown, at the non-superconductive temperature of – 175 C there is a noticeable change in the values of the dynamic angles. (Approximately 0.06 v for the superconductor sample and 0.05 for the copper sample.) Earlier tests down to –170 C with the original lead masses in the balance, also show good results in the calculation of the gravitational constant, which changed by less than 2% from the room temperature value.

Instabilities noted at the beginning of the liquid nitrogen test of the superconductor sample warranted a repeat at the lower temperature. This was conducted immediately following the first test as not to disturb the balance. Figure 10 shows the data from the repeated run.

Figures 9 and 10 then show that the superconductor and the copper samples produced similar results at the lower temperatures.

<u>EM Modulation</u>

EM modulation tests were conducted at room temperatures and at liquid nitrogen temperatures for only the superconductor. These tests are shown in



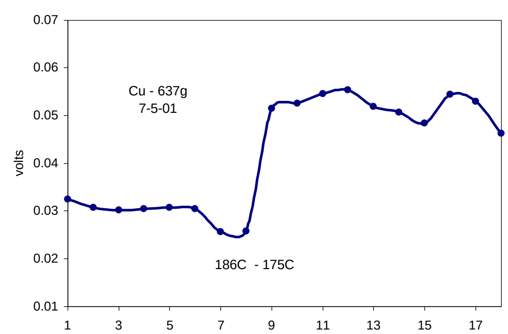


Figure 9: Dynamic Angle of copper sample (Cu) and superconductor sample (PR123) from superconductive

temperatures to non-superconductive temperature.

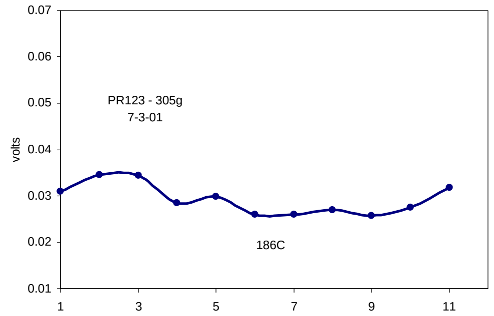
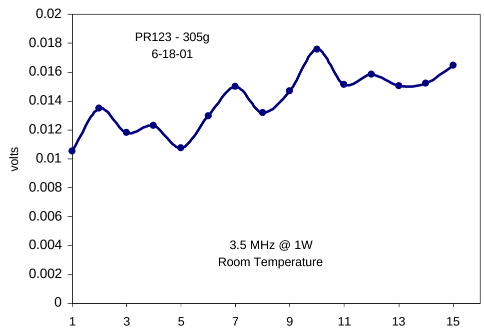


Figure 10: Dynamic Angle of the superconductor sample (PR123) at superconductive temperatures.

figure 11 and figure 12. The room temperature tests of figure 11 shows the effect of the MHz and kHz frequencies separately. In the liquid nitrogen test shown in figure 12, both the MHz and KHz frequencies are used together.

In both cases, the calculated dynamic angle increased over time. In the liquid nitrogen tests, the first two data points are with no EM modulation. This was done to detect a change before the boil off of the liquid nitrogen due to the rf heating of the iron frame, which was partially submerged in the liquid nitrogen. Rapid boil off reduced the superconductive run time from approximately six hours with no EM modulation down to two hours with EM modulation.



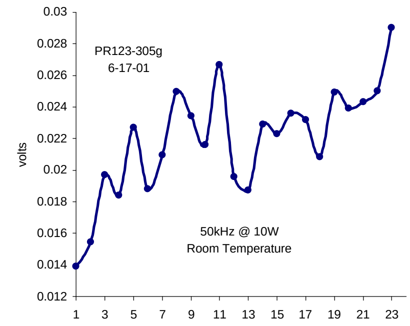


Figure 11: Dynamic Angle of the superconductor sample (PR123) at room temperatures with EM energy applied.

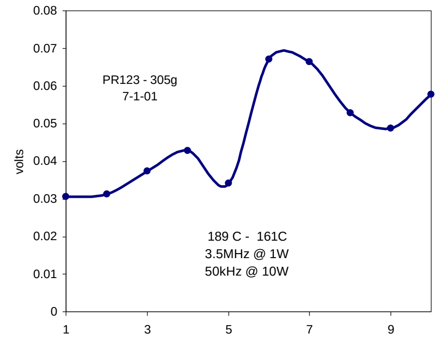


Figure 12: Dynamic Angle of the superconductor sample (PR123) at superconductive temperatures with EM energy applied.

CONCLUSIONS AND RECOMMENDATIONS

To summarize, we note that these exploratory experiments have been carried out in an attempt to quantify the effects of EM energy on a superconductor. The general conclusion is that the results of these tests gave a null result. That is, no conclusion at this time can be made to the EM effects on the superconductor. This conclusion is reached based on the increasing dynamic angle over time in both the room temperature and liquid nitrogen temperature tests.

Further, it is concluded that the balance is sensitive to mass changes at room temperature and down to approximately -175 C but not when the temperature is < -186. This conclusion was reached based on the similarities in the data for both the copper and superconductor samples in figure 9. However because no time varying temperature data was taken on these tests, further testing is required to pin point the actual shift point between –175 C and –186 C.

If a temperature at which the superconductor becomes superconductive and within the sensitivity of the balance is determined, it is recommended that non-EM modulated tests on the masses reported here and on a non-layered superconductor be conducted. Regardless of the results, a redesign of the balance is recommended to eliminate the EM modulation effects on the balance control unit and to reduce the heating effect of the modulator.

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ANTIMATTER PRODUCTION AT A POTENTIAL BOUNDARY

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ABSTRACT

Current antiproton production techniques rely on high-energy collisions between beam particles and target nuclei to produce particle and antiparticle pairs, but inherently low production and capture efficiencies render these techniques impractical for the cost-effective production of antimatter for space propulsion and other commercial applications. Based on Dirac's theory of the vacuum field, a new antimatter production concept is proposed in which particle-antiparticle pairs are created at the boundary of a steep potential step formed by the suppression of the local vacuum fields. Current antimatter production techniques are reviewed, followed by a description of Dirac's relativistic quantum theory of the vacuum state and corresponding solutions for particle tunneling and reflection from a potential barrier. The use of the Casimir effect to suppress local vacuum fields is presented as a possible technique for generating the sharp potential gradients required for particle-antiparticle pair creation.

INTRODUCTION

Present chemical engines and electric propulsion thrusters are well suited for near-Earth applications and robotic space flight, but advanced propulsion technologies must be developed to enable fast piloted and robotic deep space missions. Of all the known energy sources, none provides more specific energy than the annihilation of matter and antimatter. The energy released per kilogram of combined matter and antimatter is nearly 250 times the specific energy released in nuclear fusion, and over 8 orders of magnitude greater than the specific energy released in chemical combustion.[1] The possibility of producing photon rockets using gamma rays from electron-positron annihilation was investigated over half a century ago,[2] but the efficiency of the engines were curtailed by an inability to collimate the energetic photons. With the experimental discovery of the antiproton in 1955, attention turned to the use of proton-antiproton annihilation as an energy source for spacecraft propulsion. The higher rest mass energy of the proton-antiproton pair yields 1877 MeV per annihilation event, compared with 1.02 MeV released by electron-positron annihilation. Equally important, a significant fraction of the proton-antiproton annihilation energy appears in the kinetic energy of charged particles,[3-5] which may be collimated for direct thrust or used to heat an expellant more effectively than electron-positron gamma radiation. Several antiproton-powered rocket designs have been proposed over the past few decades, ranging from low thrust, high specific impulse pion engines to higher thrust, lower specific impulse solid and gas core thermal rockets.[6-20] Recent modeling efforts have simulated the performance of magnetically confined hydrogen plasma engines heated by charged proton-antiproton annihilation byproducts[21-24] and have investigated antiproton-boosted fission reactions as a driver for an inertial confinement fusion rocket.[25,26]

Although a number of potential antiproton propulsion concepts have been analyzed, their transition from theoretical design to experimental validation and practical use has been constrained by the prohibitive cost of creating and storing the antiprotons. The following section discusses current antiproton production methods, and outlines near-term prospects for efficient antiproton production and storage.

Current Antiproton Production Methods

The two leading facilities for antiproton production and storage are the European Laboratory for Particle Physics (formerly CERN, the Center for European Nuclear Research) in Geneva, and the Fermi National Accelerator Laboratory (FNAL) in the United States. At the

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CERN facility, protons are accelerated by a linear accelerator to 50 MeV ($8x10^{-12}$ J), injected into a booster ring and accelerated to 800 MeV, and then sent to a proton synchrotron, where they are further accelerated to 26 GeV. The high-energy protons are then focused into a 2-mm beam and directed into a 3-mm diameter, 11-cm long copper wire target. The relativistic protons collide with the target nuclei, producing a spray of gammas, pions, kaons, and baryons, including antiprotons. On leaving the target, the antiprotons have a peak momentum of 3.5 GeV/c, corresponding to a peak energy of roughly 3 GeV. A short focal length, pulsed magnetic horn is used to capture antiprotons that have momenta within 1.5% of their peak value, at angles up to 50 mrad from the target centerline. The captured antiprotons are sent to a storage ring in bursts of about 10^7 antiprotons every few seconds, and around 10^{11} antiprotons can be accumulated before space charge effects scatter the circulating beam. The antiprotons are sent back to the proton synchrotron, which decelerates them to an energy of 200 MeV, and then to the low energy antiproton ring, where the circulating beam is further decelerated, stochastically cooled, and stored. Similar techniques are used to create antiprotons at FNAL.

During the high-energy collisions, approximately one antiproton is created for every 10^5-10^6 high-energy protons incident on the target. The energy efficiency, defined as the energy released in a proton-antiproton annihilation event (1.88 GeV at rest) divided by the energy required to create an antiproton, is abysmally low. On average, CERN creates 1 antiproton for every $2.5x10^6$ protons; at an average energy of 26 GeV per proton, the corresponding energy efficiency is approximately $3x10^{-8}$. FNAL, which uses a 120 GeV proton beam to strike the target, creates 1 antiproton for every $3.3x10^4$ protons, corresponding to an energy efficiency of around $4x10^{-7}$. Assuming a "wall-plug" efficiency for each accelerator of around 5%, the total antiproton production efficiencies are roughly $1.5x10^{-9}$ for CERN and $2x10^{-8}$ for FNAL. The total annihilation energy contained in 1-mg of antiprotons (roughly $6x10^{20}$ antiprotons) is $1.8x10^{11}$ J; an efficiency of $1.5x10^{-9}$ means that it would take nearly $1.2x10^{20}$ J ($3.3x10^{13}$ kW-hr) to create 1 mg of antiprotons. Assuming a conservative energy cost of \$0.05/kW-hr, the estimated production cost is a staggering $\$1.6x10^{11}$ per milligram of antiprotons. Most antimatter propulsion concepts require milligrams to grams of antiprotons, indicating that current antiproton production techniques are inadequate for future spacecraft propulsion applications. However, as discussed by Forward[1] and Schmidt *et al.*,[27] neither CERN nor FNAL were designed as dedicated antiproton production facilities. As such, a number of upgrades to the current facilities could be made to improve antiproton production and storage capabilities. Magnetic fields produced by electric currents flowing through the metal wire targets could be used to keep the spray of antiprotons closer to the target axis, reducing their angular spread. Multiple targets could be employed, with magnetic lenses used to refocus the antiprotons between each section. Angular capture efficiencies could be improved by going to higher beam energies, creating a forward-peaked distribution that allows more antiprotons to be captured. Material lenses could be replaced with current-carrying plasma lenses, which are less likely to absorb the antiprotons and would not need active cooling. Using linear rather than synchrotron accelerators to produce the initial high-energy proton beams could increase the accelerator energy efficiency by an order of magnitude over the current 5%wall plug efficiencies.

Taken together, the potential facility improvements could result in the yearly production and storage of microgram quantities of antiprotons at a potential cost[27] of around $\$6.4x10^6/\mu g$ ($\$6.4x10^9$/mg). While these production numbers and costs are approaching those required for ground testing antimatter propulsion concepts, they are not adequate for antimatter-based propulsion systems. Forward[1,20] calculates that antiproton propulsion becomes cost competitive with chemical propellant systems at an antiproton production cost of approximately $\$10^7$/mg, and antiproton propulsion becomes the most cost effective propulsion source available if the production costs can be lowered to $\$2x10^6$/mg. Because the near term facility modifications outlined above are unlikely to produce the necessary reduction in antiproton production costs, a number of alternative antiproton production techniques have been suggested. Chapline[28] has proposed colliding heavy ion beams, made up of singly charged uranium atoms, to produce up to 10^{18} antiprotons/sec. Unfortunately, the antiprotons will be emitted isotropically and will be very difficult to collect. Equally problematic, the colliding heavy ion beams will produce a significant amount of nuclear debris and radiation, which would have to be safely and efficiently removed from the spray of antiprotons. Cassenti[29] has suggested that the pions generated during the collision of high-energy protons with heavy target nuclei could be redirected toward the target to increase the number of antiprotons and improve the efficiency of current antiproton production techniques. Although promising, the collection and redirection of the pions and antiprotons remains a major challenge to this concept.

Hora[30] proposed the use of a high intensity laser that could generate sufficiently strong electric fields to produce proton-antiproton pairs from the vacuum, and Crowe[31] separately proposed the use of high intensity lasers to produce electron-positron pairs. At present, however, there are no known lasers that can produce the high intensity electric fields needed for pair production. Forward[1,20] and Haloulakos and Ayotte[32] have investigated the possibility of building and operating an antiproton factory in space, where the proton accelerator could be powered by solar energy. However, the estimated cost to produce and store the antiprotons is still nearly $\$10^9$/mg, which is a factor of 10^2 too high for cost-effective space propulsion applications.[32]

Rather than rely on high-energy proton beam collisions with a stationary target, this paper outlines a new concept that may lead to the more efficient production of antimatter in quantities sufficient for propulsion and other commercial applications. The proposed technique is based upon particle-antiparticle pair production at the steep potential boundary created by the suppression of local vacuum field energies. The premise is based on Dirac's relativistic theory of the vacuum state, which is outlined in the following section. The theory underlying particle-antiparticle pair creation at a potential boundary is discussed, followed by an explanation of the technique proposed to create the required potential step. The paper concludes with an overview of an experimental approach designed to demonstrate the feasibility of this new antimatter production concept.

DIRAC'S THEORY OF THE VACUUM STATE

Dirac was the first to develop a relativistic wave equation that correctly describes the interaction of spin-1/2 particles, such as electrons and protons.[33] Dirac's equation contains both positive and negative energy solutions, the latter identified with the continuum energy of the vacuum state (Fig. 1). As defined by Dirac, the vacuum state is characterized by the absence of all real electrons in positive energy states, but has electrons filling all negative energy states (the "Dirac sea"). Because of the Pauli exclusion principle, real electrons cannot transition into negative energy states since all such states are already occupied; however, an electron in a negative energy state can absorb radiation and transition to a positive energy state, leaving behind a "hole" in the negative energy continuum. The hole behaves like a positive electron and represents the antiparticle of the electron. The creation of an electron and an antielectron (positron) is identified as pair creation and requires a minimum energy of $2m_oc^2$. Pair annihilation occurs when an electron drops back into the (unoccupied) hole, with the resulting transition energy emitted as radiation.

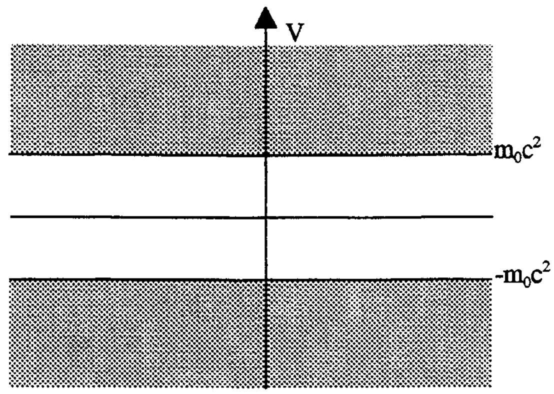

Figure 1. Energy Levels of the Dirac Equation

More generally, in Dirac's theory the vacuum represents a continuum of negative energy states occupied by negative energy particles. Pair creation is the process in which sufficient energy is given to a particle in the negative energy state to raise it to a positive energy state (creating a real particle and leaving behind a hole, or antiparticle); annihilation occurs when the particle falls back into the hole, with the energy carried away as radiation. The vacuum itself should have zero energy, zero mass, and no charge, which is clearly not satisfied by the simple form of the theory. Instead, there are infinitely many negative energy states, which together have an infinitely large negative energy, and, in the case of electrons populating the negative energy continuum, an infinitely large negative charge. These difficulties are removed by renormalizing the zero point of charge and energy in such a way that the vacuum has no mass, energy, or charge. This renormalization process is not pleasing from an aesthetic viewpoint, but it does satisfy the constraint that only departures from the vacuum state are observable and hence relevant.

TUNNELING AND POTENTIAL BARRIERS

Related to Dirac's theory of the vacuum is the quantum mechanical process of particle tunneling in the presence of a steep potential step. An overview of this process is provided by Greiner,[34] the salient features of which are given here.

Consider a spin-1/2 particle (for example, an electron or proton) with energy, E, and momentum, p, traveling along the z-axis (Figure 2). The particle encounters a step potential of magnitude V_0 that rises to full value in a distance equal to the Compton wavelength of the particle, λ_c:

$$\lambda_c = \frac{h}{m_0 c} \tag{1}$$

where h is Planck's constant (6.626×10^{-34} J-s), m_0 is the particle rest mass, and c is the speed of light.

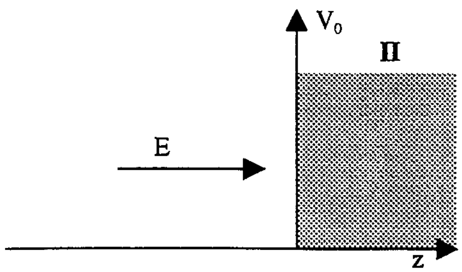

Figure 2. Particle incident on a potential step.

The Dirac equation describing the propagation of the particle in Region I is:

$$i\hbar\frac{\partial\psi}{\partial t}=\left[\frac{\hbar c}{i}\left(\hat{\alpha}_1\frac{\partial}{\partial x^1}+\hat{\alpha}_2\frac{\partial}{\partial x^2}+\hat{\alpha}_3\frac{\partial}{\partial x^3}\right)+\hat{\beta}m_0c^2\right]\psi=H_f\psi \quad (2)$$

where ψ is the particle wave function, $\hbar$ is the reduced Planck constant ($h/2\pi$), H_f is the Hamiltonian, and $\hat{\alpha},\hat{\beta}$ are the standard Dirac matrices. Noting that the momentum operator $\bar{p}$ is given by:

$$\bar{p}=\frac{\hbar c}{i}\left(\hat{\alpha}_1\frac{\partial}{\partial x^1}+\hat{\alpha}_2\frac{\partial}{\partial x^2}+\hat{\alpha}_3\frac{\partial}{\partial x^3}\right)=\frac{\hbar}{i}\nabla \quad (3)$$

the Dirac equation can be written in the more compact form:

$$i\hbar\frac{\partial\psi}{\partial t}=\left[c(\hat{\alpha}\cdot\bar{p})+\hat{\beta}m_0c^2\right]\psi=H_f\psi \quad (4)$$

The Hamiltonian for Region I (zero potential) is the total particle energy, E, while in Region II the Hamiltonian becomes ($E-V_0$). The Dirac equation for a particle wave traveling along the +z direction in Region I is then:

$$\left[c(\hat{\alpha}_3\cdot\bar{p}_1)+\hat{\beta}m_0c^2\right]\psi=(E-V_0)\psi \quad (5)$$

In Region II, the Dirac equation for the traveling particle wave becomes:

$$\left[c(\hat{\alpha}_3\cdot\bar{p}_1)+\hat{\beta}m_0c^2\right]\psi=E\psi \quad (6)$$

The solution for the particle wave function in Region I is:

$$\psi_I=A\begin{pmatrix}1\\0\\\dfrac{p_1c}{E+m_0c^2}\\0\end{pmatrix}\exp\left[\frac{ip_1z}{\hbar}\right] \quad (7)$$

where A is a constant and the particle momentum, p_1c, is given by:

$$p_1c=\sqrt{E^2-m_0^2c^4} \quad (8)$$

At the potential boundary, part of the particle wave will be reflected and part will be transmitted. The reflected wave solution in Region I is:

$$\psi_I^r=B\begin{pmatrix}1\\0\\\dfrac{-p_1c}{E+m_0c^2}\\0\end{pmatrix}\exp\left[\frac{-ip_1z}{\hbar}\right] \quad (9)$$

and the transmitted solution in Region II is:

$$\psi_{II}=D\begin{pmatrix}1\\0\\\dfrac{-p_2c}{V_0-E-m_0c^2}\\ \end{pmatrix}\exp\left[\frac{ip_2z}{\hbar}\right] \quad (10)$$

where again B and D are constants. The particle momentum in Region II is given by:

$$p_2c=\sqrt{(E-V_0)^2-m_0^2c^4} \quad (11)$$

The incident and reflected wave functions must equal the transmitted wave function at the step boundary ($z=0$):

$$\psi_I\big|_{z=0}+\psi_I^r\big|_{z=0}=\psi_{II}\big|_{z=0} \quad (12)$$

from which the following conditions are obtained for the coefficients A, B and D:

$$A+B=D \quad (13)$$

$$\begin{aligned}A-B&=-D\frac{p_2}{p_1}\left(\frac{E+m_0c^2}{V_0-E-m_0c^2}\right)\\&=-D\sqrt{\frac{(V_0-E+m_0c^2)(E+m_0c^2)}{(V_0-E-m_0c^2)(E-m_0c^2)}}=-D\gamma\end{aligned} \quad (14)$$

where γ is defined as:

$$\gamma=\sqrt{\frac{(V_0-E+m_0c^2)(E+m_0c^2)}{(V_0-E-m_0c^2)(E-m_0c^2)}} \quad (15)$$

Upon rearrangement, Equations 13 and 14 yield:

$$\frac{B}{A}=\left(\frac{1-\gamma}{1+\gamma}\right) \tag{16}$$

Dividing Equation 14 by the coefficient A and substituting Equation 16 for (B/A) yields:

$$\frac{D}{A}=\frac{2}{1-\gamma} \tag{17}$$

The particle current j is defined to be:

$$j(z)=c\psi^{\dagger}(z)\hat{\alpha}\psi(z) \tag{18}$$

where $\psi^{\dagger}(z)$ is the adjoint of $\psi(z)$. The values of $\psi^{\dagger}\hat{\alpha}$ in Region I are:

$$\begin{aligned}
\psi_I^{\dagger}\hat{\alpha}_1 &= A^*\left(0,\frac{p_1c}{E+m_0c^2},0,1\right)\exp\left[\frac{-ip_1z}{\hbar}\right]\\
\psi_I^{\dagger}\hat{\alpha}_2 &= A^*\left(0,-i\frac{p_2c}{E+m_0c^2},0,-i\right)\exp\left[\frac{-ip_1z}{\hbar}\right]\\
\psi_I^{\dagger}\hat{\alpha}_3 &= A^*\left(\frac{p_1c}{E+m_0c^2},0,1,0\right)\exp\left[\frac{-ip_1z}{\hbar}\right]
\end{aligned} \tag{19}$$

from which j_I, the incident particle current in Region I, is:

$$j_I=-AA^*\frac{2p_1c^2}{E+m_0c^2} \tag{20}$$

Similarly, the reflected (j_I^r) and transmitted (j_{II}) particle currents are:

$$j_I^r=-BB^*\frac{2p_1c^2}{E+m_0c^2} \tag{21}$$

$$j_{II}=DD^*\left(\frac{-2p_1c^2}{V_0-E-m_0c^2}\right) \tag{22}$$

Equations 20-22 can now be used to calculate the reflection and transmission coefficients for the particle wave function impacting the potential boundary. Taking the ratio of the reflected current to the incident particle current yields:

$$\frac{|j_I^r|}{|j_I|}=\left|\frac{BB^*\dfrac{2p_1c^2}{E+m_0c^2}}{AA^*\dfrac{2p_1c^2}{E+m_0c^2}}\right|=\left|\frac{BB^*}{AA^*}\right|=\left|\frac{B^2}{A^2}\right|=\frac{(1+\gamma)^2}{(1-\gamma)^2} \tag{23}$$

The ratio of the transmitted current to the incident current is given by:

$$\frac{|j_{II}|}{|j_I|}=\left|\frac{DD^*\dfrac{2p_2c^2}{V_0-E-m_0c^2}}{AA^*\dfrac{2p_1c^2}{E+m_0c^2}}\right|=\left|\frac{DD^*}{AA^*}\right|\gamma$$
$$=\left|\frac{D^2}{A^2}\right|\gamma=\frac{4\gamma}{(1-\gamma)^2} \tag{24}$$

For a potential step $V_0 > (E+m_0c^2)$, the value $\gamma>1$. From Equation 23, this indicates that the reflected particle current exceeds the incident particle current in Region I ($|j_I^r|>|j_I|$). It appears that electrons are entering Region I from Region II, but there are no electrons initially present in Region II. This result, known as Klein's Paradox, is most often interpreted as particle-antiparticle pair creation at the potential boundary.

Discussion of Results.

Applying a potential $V_0 > E + m_0c^2$ raises the energy in Region II sufficiently for there to be an overlap between the negative energy continuum (z>0) and the positive energy continuum (z<0), as shown in Figure 3:

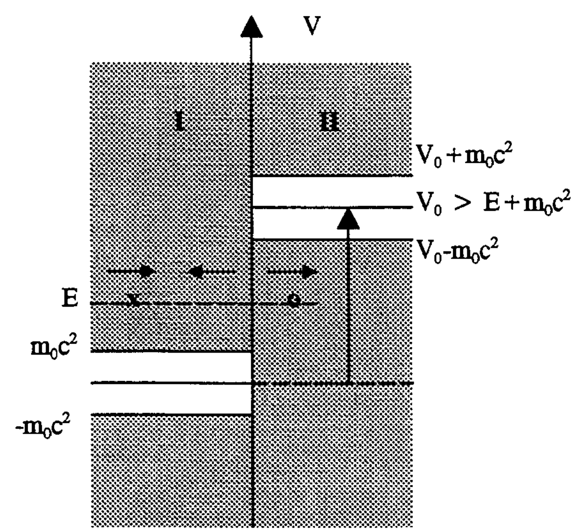

Figure 3. Energy Continuum of the Dirac Equation at a Potential Barrier.[34] (x) = particle, (o) = antiparticle

When $V_0 > E + m_0c^2$, the particles striking the barrier from the left are able to knock additional particles out of the vacuum on the right, leading to an antiparticle current flowing from the left to the right in Region II and a particle current flowing from right to left in Region I. This pair creation is depicted schematically in Figure 3, with the additional particles entering Region I from the right accounting for the increase in return current. As noted by Greiner,[34] this process is most readily understood as particle-antiparticle pair creation at the potential barrier and is related to the decay of the vacuum in the presence of supercritical fields. When the potential function V_0 is less than $E + m_0c^2$, the particle momentum in Region II is imaginary (Eq. 11) and the wave solution will be exponentially damped (Eq. 10); all of the incident current is then reflected back into Region I, and no particle current is transmitted into Region II. It is only when $V_0 > E + m_0c^2$ that the momentum in Region II becomes real and the particle wave function in Region II again becomes a traveling wave.

The above derivations may be summarized as follows:

- The Dirac equation is used to represent the evolution of spin-1/2 particle wave functions.
- Dirac's equation permits both positive and negative energy solutions; the negative energy states are filled with virtual particles, which prevent particle transitions from positive energy states to negative energy states via the Pauli exclusion principle.
- Particles will be completely reflected from a potential barrier (V_0) when their energy $E < V_0$; the transmitted particle wavefunction is exponentially damped within the potential barrier.
- For potential steps with $V_0 > E + m_0c^2$, an incident particle will induce pair creation at the potential boundary, resulting in a (real) return particle current and a (real) transmitted antiparticle current.

The question now arises as to whether this effect can actually be applied to the production of antimatter. The potential step must be greater than $E + m_0c^2$, where E is the total particle energy (rest mass plus kinetic), and the potential must rise to its full value over a distance comparable to the Compton wavelength of the particle, $h/(m_0c)$. For an electron, the minimum potential step height is 1.02 MeV (plus the kinetic energy of the electron), and the Compton wavelength is approximately 2.4×10^{-12} m. For a proton, the minimum potential step height is 1876 MeV and the Compton wavelength is approximately 1.3×10^{-16} m. These supercritical potentials are too large to be generated over such short distances using laboratory electric fields, but there may be another option: rather than use externally applied fields to raise the vacuum energy in Region II, it may be possible to use the Casimir effect to lower the vacuum energy in Region I. This concept, shown schematically in Figure 4, may be able to produce the same pair creation effects depicted in Figure 3 without requiring the application of supercritical external fields. A brief discussion of the Casimir effect is provided below, followed by an outline of a possible experimental test of the proposed antimatter production mechanism.

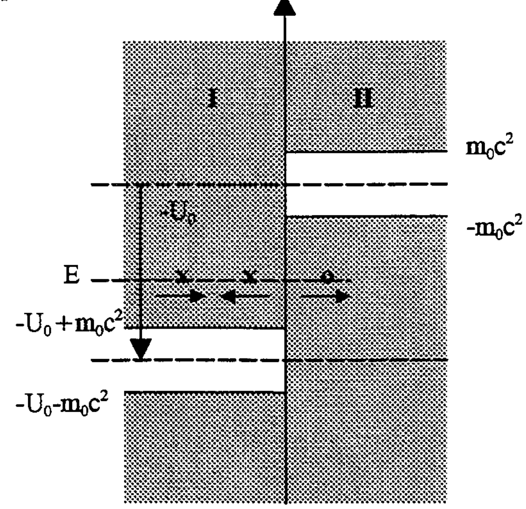

Figure 4. Lowering the vacuum energy via the Casimir effect.

VACUUM FIELDS AND THE CASIMIR EFFECT

Dirac's vacuum is a negative energy continuum populated by particles that prevent positive energy particles from transitioning into the negative energy states. To avoid obvious problems associated with infinite vacuum charges and energies, the vacuum state is renormalized to zero; only deviations from the vacuum state are measurable. As such, the potential step shown in Figure 3 represents an applied field measured with respect to the background vacuum; the energy in Region II has been raised by the applied field such that the negative energy states now overlap the positive energy states in Region I. However, raising the background vacuum in Region II requires a tremendous amount of energy ($V_0>E+m_0c^2$) over a very small distance, which is clearly beyond present capabilities. Rather than raising the vacuum energy in Region II, it is proposed that the same effect can be generated by suppressing the relative vacuum energy in Region I, as shown in Figure 4. This process can be viewed either as lowering the positive energy states such that they now overlap with the negative energy states in Region II, or the background vacuum in Region I can be renormalized to zero to yield an energy diagram similar to Figure 3. In either instance, a particle wave traveling from Region I into Region II will be described by the same solutions outlined in the section above, leading to particle-antiparticle pair creation at the potential boundary. Unlike Figure 3, pair production is achieved not by raising the potential but by lowering the relative vacuum energy, an effect that might be accomplished through the use of a Casimir cavity.

Before discussing the Casimir effect, it should be noted that Dirac's interpretation of the vacuum as a continuum of negative energy states occupied by negative energy particles, though somewhat dated, is not in disagreement with the current quantum electrodynamic (QED) interpretation of the vacuum as an infinite sea of electromagnetic radiation populated with virtual particle pairs. Because exchange interactions occur in Dirac's theory, virtual electron-positron pairs are continuously created and annihilated in the vacuum; an electron in a bound or free state can fill a virtual hole in the Dirac sea, with a virtual electron taking its place. Renormalization of the vacuum energy and charge is required both in Dirac's original theory and in QED, and as noted by Greiner,[34] the physical content of the Dirac theory forms the basis of current quantum electrodynamics. This is mentioned because the Casimir effect is generally discussed in terms of the QED interpretation of the vacuum state, and it is necessary to point out that both the Dirac and QED vacuum interpretations are complementary.

The Casimir Effect

As in the Dirac theory, the vacuum state in quantum electrodynamics is interpreted to be the state of lowest energy. This lowest energy state is not at rest, but fluctuates with a "zero-point" energy.[35-39] The vacuum fluctuations have measurable effects, including the experimentally observed Lamb-Retherford shift between the s and p energy levels of the hydrogen atom, and the attractive Casimir force that occurs between closely spaced uncharged conductors. As discussed by Mostepanenko *et al.*,[35] the Casimir effect can be accounted for by assuming the force is a consequence of the separation-dependent vacuum field energy trapped between the conductors. For example, assume that two square conducting plates with side dimensions L, separated by a distance z, are placed in a vacuum. In the QED interpretation, the vacuum is teeming with electromagnetic radiation (although mathematically the vacuum state is renormalized to zero), hence the plates may be considered to constitute a cavity that supports vacuum fluctuation modes with wave numbers down to about z^{-1}. The vacuum energy trapped between the plates is approximately given by:

$$U = \sum_{k=\frac{1}{2}}^{K} \frac{1}{2}\hbar\omega \approx (L^2 z)\int_{z^{-1}}^{K} \hbar c k k^2 dk \cong \frac{1}{4} L^2 \hbar c\left[zK^4 - z^{-3}\right] = U_U - U_L \tag{25}$$

where U_U is the upper energy bound, U_L is the lower energy bound, and K represents a high frequency cut-off to make the total energy finite. The negative rate of change of the lower cut-off energy U_L with separation z constitutes a force of attraction, F, per unit area, given by:

$$\frac{F}{A} = -\frac{1}{L^2}\frac{dU_L}{dz} \approx \frac{\hbar c}{z^4} \tag{26}$$

A more careful analysis leads to the exact relationship for the force per unit area between the parallel conducting plates:[39]

$$\frac{F}{A} = \frac{\pi^2}{240}\frac{\hbar c}{z^4} \tag{27}$$

In other words, the vacuum energy density between the plates is lower than the vacuum energy density outside the plates by an amount equal to the right hand side of Equation 27. For reasonable plate sizes and small separation distances, the change in the vacuum energy density can be appreciable. Assuming the plates have length L=0.1 m and are separated by a distance of 1-μm (10^{-6} m), the change in the vacuum energy density is approximately $1.3\text{x}10^{-4}$ J/m^3, corresponding to an inward pressure of $1.3\text{x}10^{-4}$ N/m^2 on the plates. For a separation distance of 0.1-μm (10^{-7} m), the change in the vacuum energy density is equal to 1.3 J/m^3, corresponding to an inward pressure of 1.3 N/m^2. The calculations can be carried down to separation distances that are approximately equal to the cut-off wavelength of the conducting material, at which point the plates can no longer be considered good electromagnetic reflectors.

Equations 26 and 27 demonstrate that the vacuum energy density between the conducting plates is lower than the external vacuum energy density. Multiplying Equation 27 by the plate surface area (L^2) and the separation distance between the plates (z) yields an expression relating the decrease in the vacuum energy between the plates compared to the external vacuum field energy:

$$\Delta E_{VAC} = -\frac{\pi^2}{720}\frac{\hbar c L^2}{z^3} \tag{28}$$

For square plate dimensions of L = 0.1 m and a separation distance of 0.1-μm, the change in vacuum energy is calculated to be $4.3\text{x}10^{-9}$ J, or roughly $2.7\text{x}10^{10}$ eV (27 GeV). The vacuum energy between the plates is thus substantially lower than the vacuum energy external to the plates, or conversely, if the vacuum energy between the plates is renormalized to zero, the vacuum energy external to the plates is substantially higher than the vacuum energy between the plates. By adjusting the plate dimensions and separation distance, it may thus be possible to significantly suppress the vacuum energy in a given region and generate a condition similar to that shown in Figure 4. A particle generated in the suppressed vacuum fields of Region I will see a higher vacuum field energy outside of the plates, and if the relative change in the vacuum energy exceeds $E+m_0c^2$, it may be possible to generate particle-antiparticle pairs at the vacuum energy step. Because the Dirac solutions hold equally well for electrons or protons, the possibility exists that low energy proton-antiproton pairs might be created at the steep potential boundary created by vacuum field suppression in a Casimir cavity.

Creating a Potential Gradient

The Casimir effect provides an avenue for creating sufficiently large potential steps, but the question arises as to whether these steps can be generated over a distance comparable to the Compton wavelength of the particle. From Equation 1, the Compton wavelength for electrons is 2.42×10^{-12} m, while for protons the Compton wavelength is 1.32×10^{-15} m. Either distance is several orders of magnitude smaller than any realistic plate thickness separating the interior and exterior vacuum fields, hence typical flat plates will not provide a sufficiently steep potential step for pair creation to occur.

A possible solution to this dilemma is to create a suitable potential gradient over a distance larger than the Compton wavelength, such that the required step change in potential occurs over a distance comparable to the Compton wavelength. Assuming the required potential step has magnitude V and the change in vacuum field energy due to the Casimir effect has magnitude ΔE_{vac}, the gradient relation can be expressed:

$$\frac{V}{\lambda_c} \approx \frac{\Delta E_{vac}}{d} \tag{29}$$

where λ_c is the Compton wavelength of the particle and d is the plate thickness, or more properly the thickness of the region over which the change in vacuum field energy occurs. For pair production to occur at the step boundary, the potential V must exceed $E+m_0c^2$, where E is the total energy of the particle (rest mass plus kinetic energy). Assuming the particle kinetic energy at the boundary is small compared to its rest mass energy, the requirement for V becomes:

$$V \geq 2m_0c^2 \tag{30}$$

Inserting Equations 28 and 30 into Equation 29 yields the following expression for the plate area, thickness, and separation as a function of particle mass and Compton wavelength:

$$\frac{2m_0c^2}{\lambda_c} \approx \frac{\pi^2\hbar c L^2}{720 z^3 d} \tag{31}$$

which reduces to:

$$\frac{L^2}{z^3 d} \approx 4.15 \times 10^{44} \frac{m_0}{\lambda_c} \tag{32}$$

Equation 32 expresses necessary conditions for a flat parallel plate geometry to form a sufficiently steep potential gradient for particle-antiparticle pair production to occur. For electrons, this condition can be written:

$$\frac{L^2}{z^3 d} \approx 1.56 \times 10^{26} (m^{-2}) \tag{33}$$

Assuming a plate separation distance $z = 10^{-7}$ m and a gradient length $d = 10^{-6}$ m, the required plate area, L^2, is around 0.156 m^2; for square plates this corresponds to a side length of approximately 0.4 m. Plates of this size and flatness are well within current manufacturing capabilities, offering some encouragement for experimental verification of the proposed concept. For protons,

$$\frac{L^2}{z^3 d} \approx 5.26 \times 10^{32} (m^{-2}) \tag{34}$$

Using the same plate separation and gradient distances above would require a plate length of 725 m to provide a suitable potential gradient. However, a number of Casimir force experiments have been performed over the past several years with plate separations down to several nanometers, and a reasonable lower limit of 10^{-8} m can be assumed for the plate separation z. The distance over which the potential gradient is formed, d, can also be reduced by locally thinning the plate support structure; a more realistic lower bound on d is thus assumed to be 10^{-9} m. Given these values, the plate size for producing the required potential step for proton-antiproton pair production is around 0.73 m, which is difficult but not impossible to manufacture.

Ideally, the potential gradient would be formed in a region devoid of plate material; this can be accomplished by designing the Casimir plate with a small hole whose diameter is of the same order or smaller than the plate separation distance. Vacuum electromagnetic fields with wavelengths larger than the hole diameter will still be blocked by the cavity, but the potential gradient formed by the plates is now in a material-free region that more faithfully reproduces the assumptions behind Figures 3 and 4. Possible effects due to the fringing of vacuum electromagnetic fields at the hole boundaries remain to be evaluated, but this method appears promising to provide the required potential gradients in a material-free region.

Summary. In summary, it appears possible to produce a Casimir cavity geometry that will provide sufficiently steep potential gradients for particle-antiparticle pair creation. By introducing a small hole in the plate material with a diameter similar to the plate separation distance, a potential step may be created in a material-free region, as depicted in Figure 4. Electron-positron pairs and proton-antiproton pairs can conceivably be generated using this technique, with significantly less infrastructure and presumably lower cost than current antimatter production methods.

EXPERIMENTAL DESIGN

The following experiment is proposed to evaluate the possibility of producing particle-antiparticle pairs at a potential boundary created within a Casimir cavity. The proposed experiment is a modified version of a similar experiment performed by the author under a prior contract to the NASA Marshall Space Flight Center.[40] In that experiment, flat parallel plates were used to form a Casimir cavity to investigate pair creation, but the plate geometries were not properly designed to generate sharp potential gradients. Based on that effort and the additional analysis in this report, the following experiment is suggested for a proof-of-concept test.

Electron-Positron Production

To investigate the formation of electron-positron pairs, it is proposed that a Casimir cavity be constructed from two flat, square metallic plates, each with an area of 1.61×10^{-2} m^2 (L = 12.7 cm). From Equation 33, spacing the plates a distance $z = 10^{-7}$ m apart should provide a suitably steep potential gradient for electron-positron pair creation to occur. To create a material free region for the steep potential step, one plate should include a central hole, drilled perpendicular to the plate boundary, of diameter $d \leq 10^{-7}$ m; vacuum electromagnetic fields with wavelengths larger than d will still be blocked by the cavity, although there may be minor effects on the potential step due to field fringing. On the opposite plate, a small amount of radioactive material can be deposited to act as a source of electrons within the cavity; Ni^{63} is a readily available commercial source, and the kinetic energy of the emitted electrons (0.067 MeV) are sufficiently below the rest mass energy of the electron that Equation 30 remains a viable approximation. Alternatively, the metallic plate can be irradiated to produce subsequent electron emissions within the cavity.

The plate surfaces must be aligned and moved to within 10^{-7} m to form the required potential step, which can be accomplished using commercially available piezoelectric transducers. The close separation distance requires that the surface flatness of the plates not exceed 10^{-8} m, which is a stringent but commercially attainable constraint. The entire system should be mounted in a vacuum system capable of achieving a hard vacuum ($\leq 10^{-8}$ torr), and isolated from vibrations. To evaluate whether the proposed pair production method works, a small target placed outside the central plate hole can be used to intercept any positrons emitted at the potential boundary. The resulting annihilation of the positrons with the target material will produce 0.511-MeV gamma rays that can be measured with a detector located behind the target.

Proton-Antiproton Production

If successful, the experimental arrangement outlined above will demonstrate the basic feasibility of the proposed pair production process. However, for propulsion applications it is desirable to produce antiprotons rather than positrons. As previously discussed, the constraints on plate size, flatness, and separation become significantly more demanding, but remain within the capability of current manufacturing techniques. For proton-antiproton pair production, square plates with areas of 0.526 m^2 (L = 0.725 m) would have to be separated by a distance of 10^{-8} m, indicating that the surface flatness of the plates would have to be on the order of angstroms. Larger plate areas would relax this constraint by allowing larger separation distances, and the ability to machine flat surface areas must be traded against the fabrication of larger plate dimensions. The central hole diameter would again be on the order of the plate separation distance to provide a material-free potential step, and the electron source would be replaced with a proton source to provide the particles within the cavity. If this scheme is successful, the antiprotons can be captured upon exiting through the hole in the Casimir plate and stored in portable Penning traps for later use.

CONCLUDING REMARKS

A new concept has been described for creating matter-antimatter particle pairs at a steep potential boundary. The potential step is created using the Casimir effect to suppress the vacuum energy between parallel conducting plates. Preliminary calculations indicate that a sufficiently steep potential gradient can be formed for reasonable plate dimensions and separation distances. A preliminary experimental design is outlined as a proof-of-concept test for the proposed antimatter production scheme. Additional analysis remains to be performed to validate the concept, including an evaluation of material and temperature effects on the plate boundaries, the effect of fringing fields on the potential step at the plate central hole, and the consequences of imperfect parallel plate alignment on the required potential gradient. Nevertheless, based on the preliminary analysis presented in this paper, the proposed concept appears to be a potentially viable alternative to the high-energy antimatter production methods currently in use.

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GRAVITY MODIFICATION BY HIGH-TEMPERATURE SUPERCONDUCTORS

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ABSTRACT

Claims that the weight of test masses can be changed in non-relativistic experiments have been investigated. Amongst the most prominent reports has been a paper by Podkletnov & Nieminen (Physica C **203** 441, 1992); more recently, Rounds (Proc. NASA Breakthrough Propulsion Phys. Workshop, Cleveland, 297, 1998) used a simpler experimental arrangement. Both of these experiments measure the gravitational field above $YBa_2Cu_3O_{7-\delta}$ (superconducting below $T_c \approx 93K$). Podkletnov & Nieminen specify that the superconductor must be cooled below 70K, magnetically rotated at ~5000 rpm, and simultaneously levitated magnetically using two separate frequency excitations; weight changes of ~1% were reported. Rounds specifies less stringent conditions, mainly that the YBCO is cooled to 77K whilst stationary. The Rounds experiment has been repeated virtually exactly, and the Podkletnov experiment has been investigated by reproducing some of the conditions specified. No measurable gravity modification (within ±0.03%) was observed using the subset of the Podkletnov conditions, (but this does *not* preclude gravity modification arising from the full specified conditions). The Rounds configuration also has not shown any effects reliably ascribable to gravity modification, although there was unusual thermal behaviour.

1. INTRODUCTION

A number of reports recently claimed that the weight of test masses can be changed as a result of using various materials in various configurations and using various excitations. One of the most prominent of these has been that by Podkletnov and Nieminen[1]; as far as the present authors are aware, not only is this the only such paper that has appeared in a peer-reviewed journal, but it is also one of the few that cannot immediately be dismissed as spurious.

The experimental results reported by these authors appear to contradict conventional gravitational theory, because their claims amount to apparent modifications to the gravitational field in a laboratory-based system that – at face value – does not require analysis by General Relativity. This experiment is therefore potentially highly important scientifically because of the enormous technological implications for the design of current transportation vehicles and handling methods for bulk materials if gravity modification (and, in particular, gravitation reduction) were demonstrated to be feasible.

Objections to the Podkletnov and Nieminen experiment have been raised. Podesta and Bull[2] discuss the measurements[1] in terms of buoyancy effects that could be present because of the helium cooling the air surrounding the test weight. Although interesting, the air temperature required to achieve a buoyancy effect of the same magnitude as seen by Podkletnov is 150K which seems to be too low to make this a likely explanation. Unnikrishnan[3] includes a description of static levitation of a large superconducting disk that finds no gravity effect, but is more interesting for its discussion of Podkletnov's claim that the gravitational effects have no dependence on the height above the spinning disk, which appears extremely strange at first sight. This, along with Podkletnov's claims to have seen increases as well as reductions in test mass weight, confirms that the effect claimed must be "Gravity modification" rather than passive "Gravitational shielding".

Pokeltnov's report[1] was therefore selected for particular attention and experimental testing in the present work, along with a subsequent and broadly similar (though smaller) effect reported by Rounds[4]

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using a much simplified experimental arrangement. The experiment due to Rounds[4] has been repeated virtually exactly, and that due to Podkletnov[1] (experimentally much more challenging) has been investigated by examining some (although not yet all) of the conditions reported as necessary for demonstrating gravity modification.

Both of these experiments have in common that they require the gravitational field to be measured above the high-temperature superconductor $YBa_2Cu_3O_{7-\delta}$ (which is superconducting below the critical temperature $T_c \approx 93K$). In the Podkletnov arrangement, the superconductor (in the form of a multiphase circular disk having a minimum diameter 10cm) must be cooled below 70K, and magnetically rotated at high speed (e.g., 5000 rpm) and simultaneously levitated magnetically using two separate frequency excitations; weight changes (in a test mass) of the order of 1% were reported. In the Rounds arrangement, the conditions are much less stringent and mainly require the YBCO to be cooled to 77K in a stationary magnetic field.

1.1 Other claims of gravity modification

Reiss[5] has reported work on the weight of a PTFE capsule containing pellets of various materials including 2212 BSCCO high-T_c superconductor when the capsule is immersed in liquid nitrogen. All of Reiss's measurements showed the apparent weight rising with immersion time to some final figure after about 5 minutes. This rise is a result of the thermal contraction of the holder (giving a steadily reducing buoyancy in the liquid nitrogen) and shows some scatter as well as differences for different materials contained within the holder. However, Reiss's figures indicate that the capsules containing the superconductor have the biggest apparent weight increase (although not markedly bigger). Reiss interprets this in terms of the superconductor gaining weight as the inside of the sample holder cools below his superconductor's critical temperature (~95K). Reiss points out that the variation in the buoyancy drop found for his three non-superconducting materials (alumina, copper and PVC, in order of the lowest to highest drop) does not match variations in their specific heat. However, the variation in buoyancy drop *does* occur in the same order as the thermal expansion of these materials (i.e. alumina has a thermal expansion coefficient smaller than that of copper, which in turn is smaller than that of PVC). The room-temperature expansion coefficient of BSCCO (which shows the largest buoyancy drop) is roughly the same size as that of copper. Reiss's calculations show that the shrinkage of the PTFE capsule should lead to a buoyancy drop three times larger than that seen in any of his experiments; this inconsistency alone throws doubt upon gravity modification having been demonstrated conclusively.

Gravity experiments by Schnurer[6] use a 1" diameter superconducting disk attached to the top of three coils in a triangular arrangement and a metallic test mass is attached to the top of the superconductor. This assembly forms the weight on one end of a balance; the counter weight then sits on digital laboratory scales so that a weight decrease in the superconductor assembly produces an increase in the scales reading. The superconductor assembly is immersed in liquid nitrogen; once it has cooled the scales reading is noted, and power applied to the coils. The scales show an increase proportional to the sample mass. Nitrogen boiling due to the resistive heating by the coils, and possible flexing of the wires supplying the coils, may be possible explanations for these observations.

2. TESTS OF WEIGHT REDUCTION USING ROTATING SUPERCONDUCTORS

2.1 Background

Fully reproducing the Podkletnov conditions[1] is not straightforward. As far as the present authors are aware, no others have demonstrated gravity modification using similar experimental arrangements, though other partial tests[7] have been reported.

The present approach to this experiment was to start by spinning a superconductor at high speed. The basic equipment used in initial tests is illustrated in Fig. 1. A nominal 2" diameter (the die size, not the precise final disk size; where appropriate this is given in mm) granular disk fabricated ten years previously was employed. Although this disk was able to produce significant levitation (~5mm) of a 10g FeCo magnet, it could not levitate a 40g, 1" 0.45T NdFe magnet, nor could it sustainably levitate itself above an array of these magnets. A number of tests where the superconductor was cooled to 77K, spun at up to 5000 rpm, then slowed, and finally tested with a small magnet to ensure that the Meissner effect was still present, never produced any change in the test weight.

2.2 Present Project

In developing this investigation further, it was clear that reproducing the full Podkletnov conditions would take considerable time. Dr. Podkletnov has visited our laboratory to observe our experiments, and has made some helpful comments based upon his own experience[8]. The strategy adopted was as follows:

- to be limited initially to 3" diameter disks,
- to develop a melt texturing process for disk fabrication (Podkletnov partially melt textured his disks to achieve much greater levitation for the same magnetic flux density),
- to develop a new weight measurement system,
- to use permanent magnets to provide levitation and/or rotating fields, and
- to produce low field, high frequency excitation using a 13.56MHz generator.

These points will be discussed in turn below.

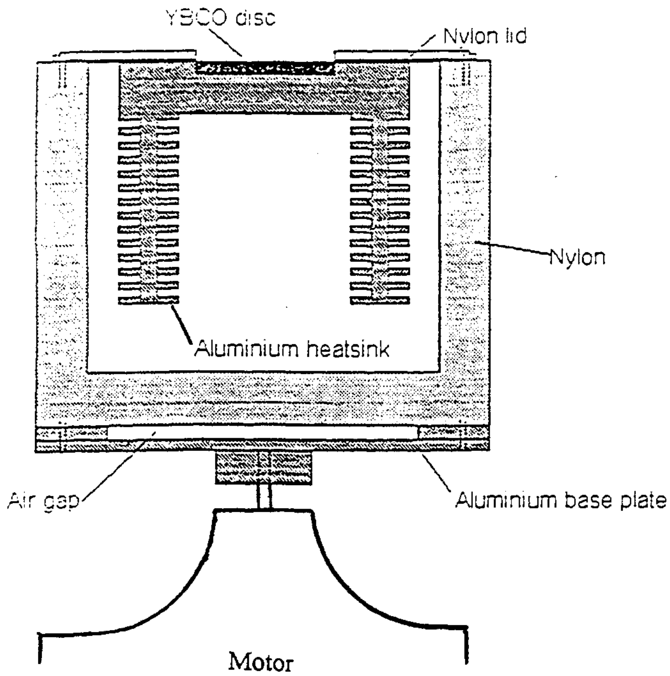

Fig. 1: *The basic gravity test equipment. The aim was to spin the nitrogen container at high speed, while keeping the superconductor below T_c*

2.2.1 Melt Texturing and Disk Fabrication

Melt texturing has been found to improve YBCO's levitation force significantly for a given field and so was developed to produce disks that could self-levitate above NdFe magnets.

When YBCO is raised above 1008°C it begins to decompose according to the reaction:

$$2YBa_2Cu_3O_6(s) \rightarrow Y_2BaCuO_5(s) + \text{copper/barium rich liquid},$$

i.e., the high temperature form of the superconducting YBCO phase decomposes to a liquid that is mostly $BaCuO_2$ and solid green phase YBCO. This reaction is partially reversible, i.e. slow cooling back through 1008°C re-forms the 123 (superconducting) phase with inclusions of the 211 (green) phase and solidified copper/barium material. The resulting YBCO is referred to as "melt textured"; essentially the grain boundaries which limit the bulk superconductivity of a granular sample have been reduced as the grains have melted into each other. Most importantly the crystal axes in a melt textured sample tend to be aligned (usually so that the larger *c*-axis is vertical) so that the sample properties are no longer an average of the good in-plane and poor out-of-plane superconductivity exhibited by YBCO.

One step further than melt texturing is top seeded melt texturing. Seeding is carried out using small 123 phase crystals with the yttrium replaced with neodymium or samarium. This substitution produces a material with the same crystal structure (except that the larger rare earths have a tendency to be disordered because their size means that they can partially substitute for barium) but having a higher decomposition temperature. These crystals when placed on the surface of an YBCO pellet above the decomposition temperature can, on cooling, seed the growth of large single domain pseudo-crystals of 123 YBCO (they are not true single crystals because of the 211 and Cu/Ba inclusions).

Practical problems such as liquid flowing out from the pellet above 1008°C can be controlled by adding extra 211 phase to increase the solid content at high temperatures, but precise temperature control, without significant temperature gradients, is necessary. (Temperature gradients lead to different crystallisation rates across the disks, causing disk cracking.)

The aim of this work was to produce 3" disks with an even distribution of reasonably sized, randomly oriented domains across their surface. Although single YBCO domains up to 70mm across have been demonstrated[9], owing to the level of furnace temperature control currently available to the present work the largest single domain produced was approximately 12mm × 12mm. In addition Podkletnov considered inter-grain junctions to be crucial to the gravity effect and we did not want to eliminate grain or domain junctions entirely.

It was found that attempting to distribute Nd123 crystals across the disk surface did not produce the even domain distribution necessary. Not all of the Nd seeds produced large domains and in any case distributing small seed crystals in a furnace at 1020°C is not an easy process. A disk resulting from multiple top seeding is shown in Fig. 2; it clearly showed visibly uneven crystal distribution, giving a levitation force varying from place to place across the disk.

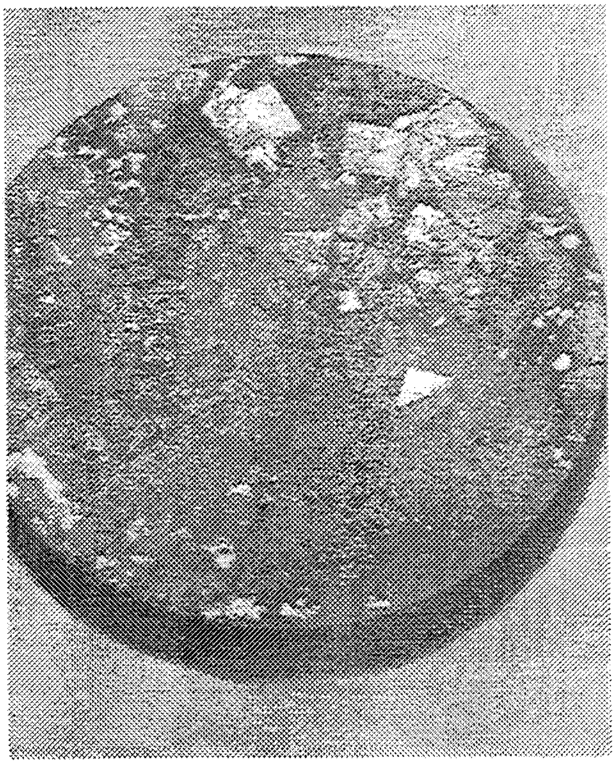

Fig. 2: Top seeded 3" disk

A better disk was produced not by seeding, but by dropping the post-decomposition temperature from the 982°C used for seeded growth to 975°C. This lower temperature produces self-seeding and smaller randomly shaped but evenly distributed domains resulted (Fig. 3). This 110g disk, following oxygenation between 500 and 200°C for a week, could self-levitate above an array of seven NdFe magnets at a height of approximately 15mm, and could levitate a single NdFe magnet plus a further 80g at 2mm above its surface.

As an alternative to homogeneous self-seeding a new process, heterogeneous self-seeding, was tried. This involves including some Nd211 phase in the Y123/211 mix so that the Nd/Y ratio was 2/98. When the disk was raised to 1100°C (above the decomposition temperature of Nd123) and then cooled to 982°C, Nd123 is able to solidify from the 211/liquid mix first. This is because of its higher decomposition temperature and because the neodymium's similar size to barium makes Nd much more soluble than Y in the melt – enhancing diffusion to a growing crystal surface. The Nd123 crystals formed in this way then act as seeds distributed evenly throughout the disk for the Y123 growth. A disk grown by this method (Fig. 4) had levitation characteristics similar to the homogeneously seeded disk; it is expected that further development of this process would lead to still higher levitation forces.

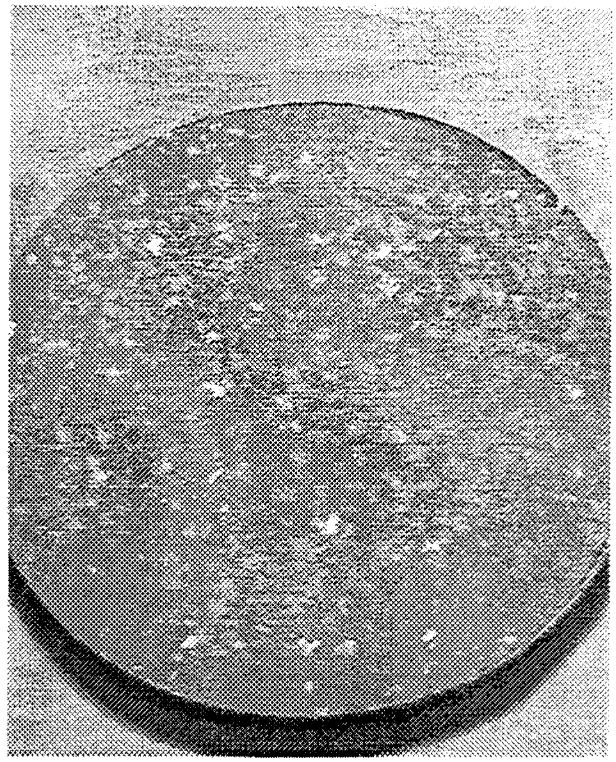

Fig. 3: Homogeneously seeded 3" disk

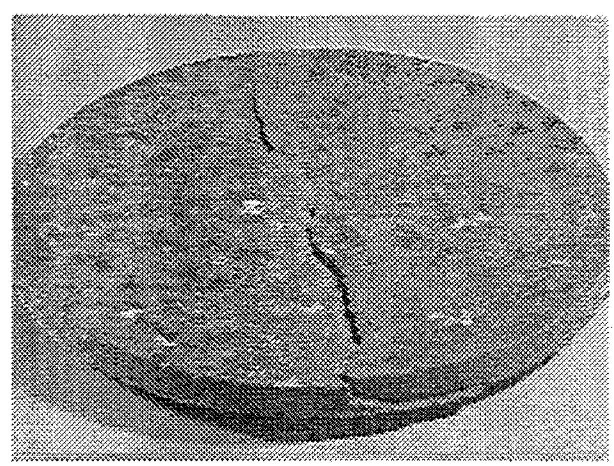

Fig. 4: Heterogeneously self-seeded 3" disk. The crystallisation is more evenly distributed with a more random orientation than the top seeded disk

The chief problem found in this work is that of disk cracking. It was found that any indication of a crack in the unfired disk that had been compacted in a die from the precursor powders using a fifty tonne hydraulic press would lead to catastrophic cracking during firing. Only one in four disks as-pressed was good enough to be fired (although unfired disks could usually be reground and pressed again). One in two that were fired held together, with or without some evidence of cracking, after melt texturing. The extra shrinkage due to the densification that occurs during melt texturing, plus the uneven crystallisation resulting from temperature gradients, puts a big strain on the mechanical stability of the disk.

One final innovation used during disk manufacture was the use of Saffil fabric (Alumina/Silica fibres pressed into a loose fabric/board) between disk and substrate on firing. This served two purposes; the main one was to ensure that disk could be separated from the substrate post partial melting. Secondly, since both aluminium and silicon chemically poison YBCO, incorporation of the fabric into the lower layer of the disk during melt texturing meant that there was a graduated poisoning of the superconductivity from top to bottom. In effect, the disks were bi-layered as specified by Podkletnov[1].

2.2.2 Experimental Apparatus

A beam balance was designed having the necessary resolution (0.004g or better for a 100g test mass, i.e. 0.004%) using a knife-edge pivot. Damping was essential, and was incorporated using a magnet that induced a Lorentz current in an aluminium plate opposing motion in proportion to velocity. The final design is shown in Fig. 5. The balance counter-mass was adjustable to give sensitivities that ranged from 1mm deflection for 0.02g difference, to 5mm deflection for 0.02g difference. The test mass used was 100g in all the tests undertaken as part of the present work, so that the best resolution obtainable was of the order of 0.004%, certainly sufficient for this application.

The cryostat body was made of aluminium and uses chemically-expanding foam as a thermal insulator. An aluminium heat-exchanger, for thermal coupling of the superconductor to the liquid nitrogen refrigerant, was also used.

Tests on this cryostat assembly showed that although it performed better than previous cryostats (fabricated from nylon) in maintaining superconductivity during static tests, after spinning at 5000 rpm and slowing to rest the superconductor had warmed above T_c (determined using the Meissner effect). Over 20 tests were performed using this cryostat (on the basis that the disk would be superconducting for at least some of the time that it was being spun) with the old 2" YBCO disk and various magnet configurations. No balance deflections were seen that could be definitely ascribed to anything except vibration and so using this configuration a gravity effect larger than 0.02% can be formally ruled out.

Following this work a foil liner was added to the cryostat between the liquid nitrogen refrigerant and the foam insulator to reduce the friction on the nitrogen during acceleration. With this liner in place and using a new partially crystallised 2" disk (an early melt-textured sample that could only levitate the NdFe magnets a few millimetres) the superconductor could be consistently accelerated to a top speed of 6000 rpm, stopped, and then still levitate a magnet afterwards.

In this new configuration 32 full runs were performed using a video camera to record any balance deflections. The kinds of magnet configurations used are illustrated in Fig. 6. In some tests the superconductor was cooled through T_c in the presence of a magnetic field ("field cooling") and in others the superconductor was cooled without a field.

One variation (two NdFe magnets held over the edge of the disk, one with north up and one with north down, and the superconductor field-cooled) seemed to show balance deviations that indicated a very small weight loss during disk acceleration and deceleration. However, the vibration produced by the rotating cryostat was such that rotation alone produced balance deviations as large as any possible gravity effect. The movements were not consistent enough to be ascribed gravity effects, which in this configuration can be formally ruled out down to 0.03%.

2.3 Experimental Results from Rotating Field Tests

The aim of this work was to rotate a levitated three inch disk. However, whilst a levitated cylindrical magnet can be freely rotated about its axis in any orientation, levitated superconducting disks resist rotation in a stationary field. Therefore, the superconductor was fixed in place at the levitation height – 10 to 20mm – above a rotating array of NdFe magnets (Fig. 7). If the superconductor was not fixed in these experiments then it tended to rotate unstably with the rotating magnets. If a container was used that only just contained the superconducting disk, then sometimes the disk was seen to rise out of the position in which it had been lodged and rotate slowly when the magnets were rotating fast.

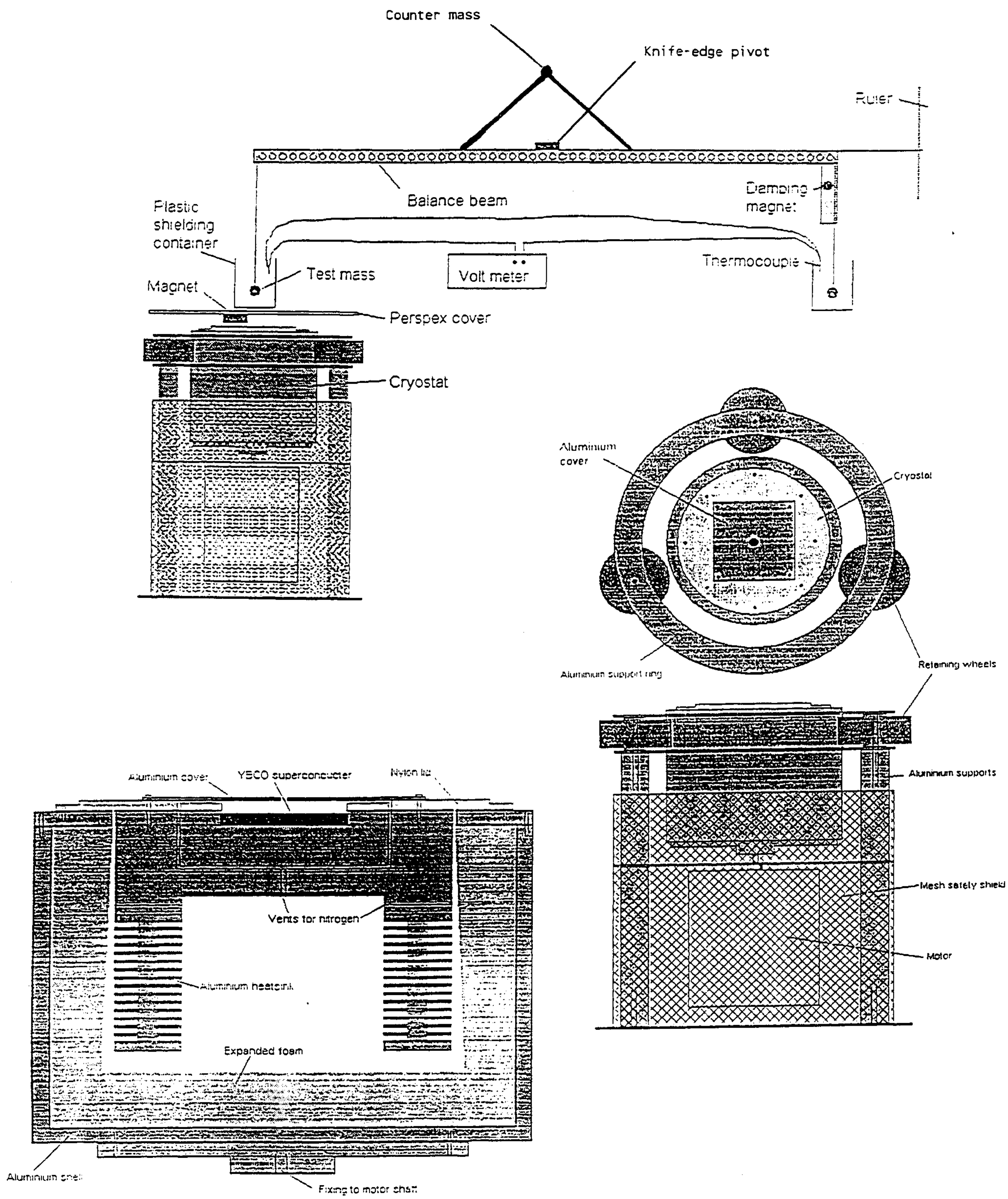

***Fig. 5:** The final assembly for the rotating disk tests*

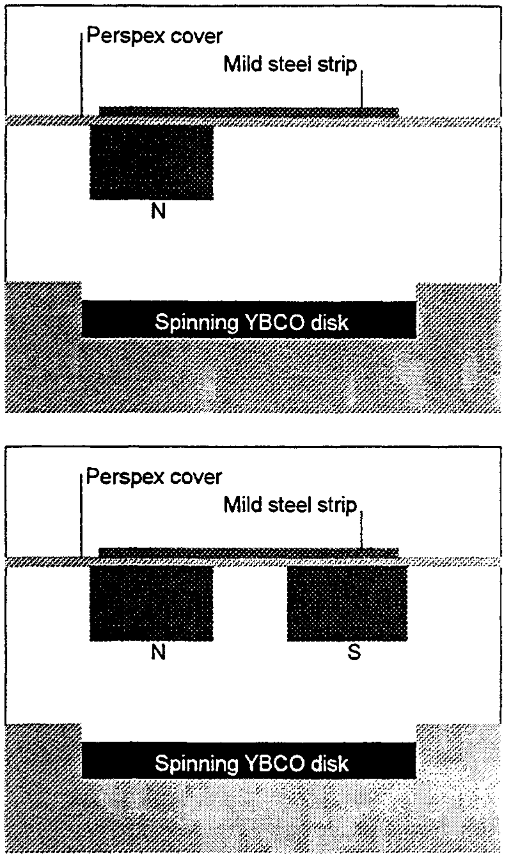

Fig. 6: Sample magnet configurations

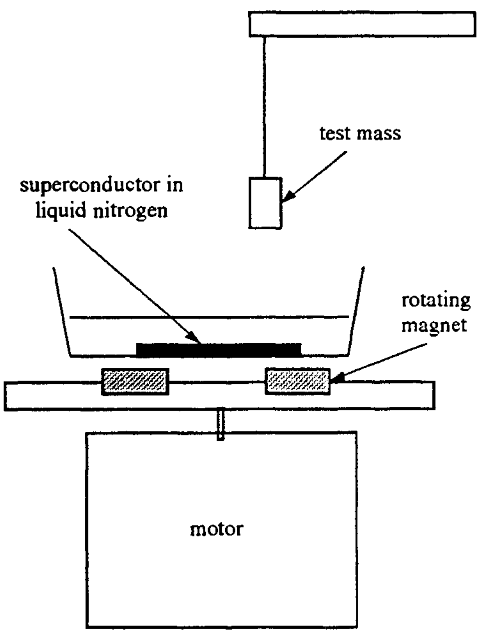

Fig. 7: Rotating field apparatus

If the superconductor was fixed in place and the container was unsecured, then when the magnet rotation speed reached around 2000 rpm the superconductor lifted the whole container with liquid nitrogen, and the container then vibrated violently. This agrees with Podkletnov's observation of his disks rising when rotated[8], but it seems more likely that this is due to Lorentz force rather than a weight loss.

When the superconductor was firmly fixed in position the field linkage between superconductor and magnets meant that at least ~10% more power was required to start the motor turning. If the superconductor was then allowed to warm through T_c with the magnets still rotating below, the motor immediately accelerated, indicating that high rotation speeds do not diminish the torque between superconductor and magnets.

Several magnet arrangements were tried (see Fig. 8). The only noticeable result arising from the different arrangements was that greater variation in the field distribution produced greater rotational stiffness of the superconductor rotating in that field. Both the homogeneously and heterogeneously self-seeded disks discussed in Section 2.2.1 were used with no obvious differences between their behaviour. No balance deflections were seen for magnet rotation speeds of up to 10000 rpm (using three pairs of opposed magnets at this speed is equivalent to a 500Hz levitation field) and a gravitational effect can be ruled out down to 0.01% (these experiments did not require the "see-saw" balance to be moved for each run, giving better resolution).

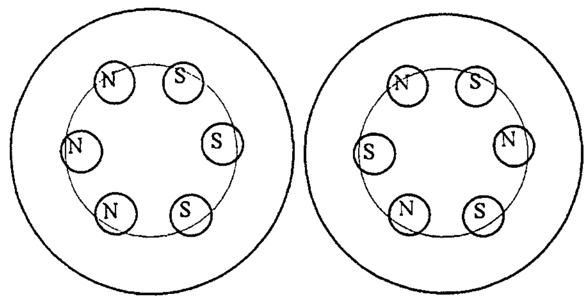

Fig. 8: Two different rotating magnet configurations tried during the present work

A variation on the above was to use four vertical magnets placed around the superconductor (Fig. 9). These magnetically contained the superconductor which was not secured in place mechanically. When the magnets below were rotating at speed the superconductor rotated slowly from the face of one containment magnet to the next. No balance deflections were observed.

Finally, five turns of copper tube were placed around the superconductor and connected through a matching unit to a 13.56MHz r.f. supply. The matching unit was designed for capacitive loads and had very little effect in minimising the reflected power. In fact the generator instrumentation suggested that for 200W forward power only 2W was absorbed by the load. Nevertheless, significant r.f. radiation was present in the vicinity of the superconductor, evidenced by the fact that the magnetic pick-up coil used for measuring rotation speed developed 3V peak to peak at r.f., swamping the output from the small magnets bonded to the rotating assembly. The r.f. had no other effect on the experiment and a gravity effect could still be ruled out to 0.01%.

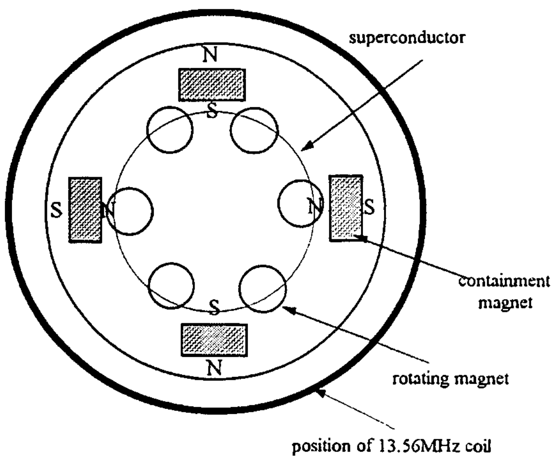

Fig. 9: *Positioning of containment magnets to prevent the superconductor rotating uncontrollably*

2.4 Discussion

It can be argued that the fact that no effect has been observed in tests such as those described above is that these tests have not fulfilled the specified conditions for a gravity effect. These are:

- A disk with a diameter greater than 100mm
- A disk containing ~ 30% non-superconducting YBCO, preferably organised into two layers
- A disk capable of self-levitation, but still containing large numbers of intergrain junctions
- An a.c. levitation field with a frequency ~10kHz
- A second a.c. excitation field with a frequency of ~1MHz, for disk rotation
- Disk rotation speeds of a few thousand rpm for large (>0.05%) gravity effects (the largest effects (>2%) were reported[1] when the disk was being decelerated at around 3000 rpm).

The difficulties involved in meeting Podkletnov's experimental conditions[1] have already been discussed. In 1999 another team[7] working on reproducing Podkletnov's work followed a broadly similar route to the present work, i.e. using melt textured disks levitated with low frequencies. This group was not able to achieve stable static levitation of large disks at frequencies greater than 600Hz, and with disks that were not melt-textured stable levitation was achieved only with frequencies up to 45Hz. No gravity effects greater than 0.000001% were found.

The present work has investigated melt-texturing technology and produced high quality bi-layer disks with a final diameter of 70mm. There seems no *a priori* reason why this process may not produce larger diameter YBCO samples, particularly if annuli are formed so that larger diameters can be achieved at similar surface areas. An annular sample may also significantly reduce cracking due to shrinkage during the sintering process.

Rotating a melt-textured bi-layer 45mm disk at up to 7500 rpm through small static magnetic fields produced no effects that could be extracted from the system noise. Nor did various arrangements of high quality bi-layer 70mm superconducting disks held at levitation height above magnets rotating at up to 10000 rpm produce any gravity effect. The addition of a small 13.56MHz excitation field did not alter this negative result.

3. ROUNDS'S EXPERIMENT: STATIC SUPERCONDUCTOR

3.1 Introduction

Rounds[4] discussed a series of experiments in which a superconductor in the presence of a permanent magnet and immersed in liquid nitrogen was slowly allowed to warm. Rounds measured the weight of the whole system, reasoning that as the superconductor passed through T_c any weight anomaly associated with the Podkletnov effect would show up as a deviation from the monotonic weight loss as the nitrogen boiled off.

Rounds found deviations from linearity in his weight against time curves for superconducting disks, and less so for copper disks. However, as with the Reiss experiment[5], it is possible to postulate a number of thermal effects that could account for this observation.

Nevertheless, the experiment was interesting and has been repeated. Exactly the same type of superconducting disk and magnet (Edmund Scientific, part numbers CR37-446 and C52-867 respectively) were used, along with a somewhat larger nitrogen container than used by Rounds and also with a thermocouple bonded to the top of the YBCO and copper disks used.

3.2 Results

The results from a typical run with a thermocouple, an YBCO disk and a magnet separated from the YBCO by 10mm of plasticine are shown in Fig. 10, and for a copper sample in Fig. 11. Different ambient conditions along with the larger container meant that our experiments took longer (210s to the prominent inflection in the curve) than those of Rounds[4] (48s) and the initial portion of the weight loss curve shows greater deviation from a straight line. However, the deviation of our weight loss curve from a straight line (Fig. 12) shows behaviour similar to that reported by Rounds, in particular an anomaly at around 20s elapsed time. Unfortunately our results contain too much scatter (probably a result of vibrations in the thermocouple wires) for us to ascribe this anomaly to anything more than noise.

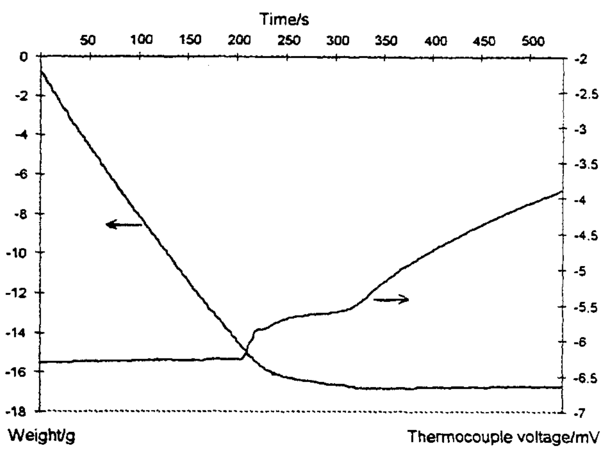

Fig. 10: The changes in weight of the experimental apparatus as nitrogen boils off in the present work

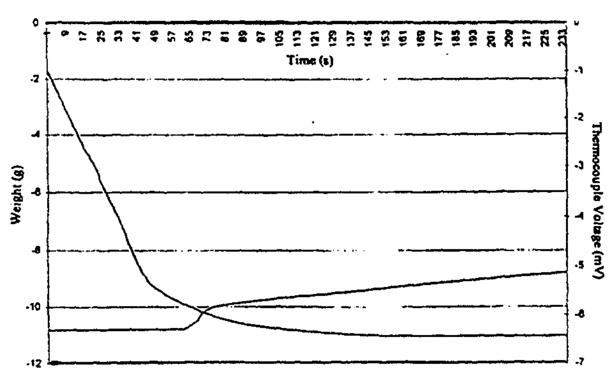

Fig. 11: As for Fig. 10 except that the YBCO disk has been replaced with a copper disk of the same size

However, the inclusion of a thermocouple does allow identification of the point at which the superconductor sample's temperature begins to rise. Inspection of Fig. 13 shows this to be after 205s, i.e. at the same time as the inflection in the weight loss curve. This concurrence can be explained by hypothesising that the heat flux into the experimental apparatus prior to 205s produced only nitrogen refrigerant boil-off, but post-205s was also required to raise the superconductor temperature, thus resulting in a slower boil-off rate.

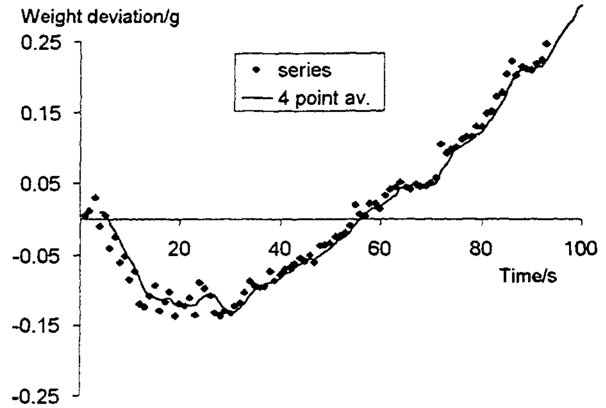

Fig. 12: The deviation from a straight line of the weight changes in Fig. 10

After 220s, as shown in Fig. 13, the rate of increase of temperature slowed dramatically, and the temperature effectively paused for a period of 10s at 93–94K. This is, of course, the critical temperature of the superconductor. Thereafter the rate of increase was slow until after 320s when no further liquid nitrogen refrigerant remained. This behaviour was reproducible using the YBCO superconductor sample but no such temperature pause was seen when the superconductor was replaced with a copper disc of similar dimensions.

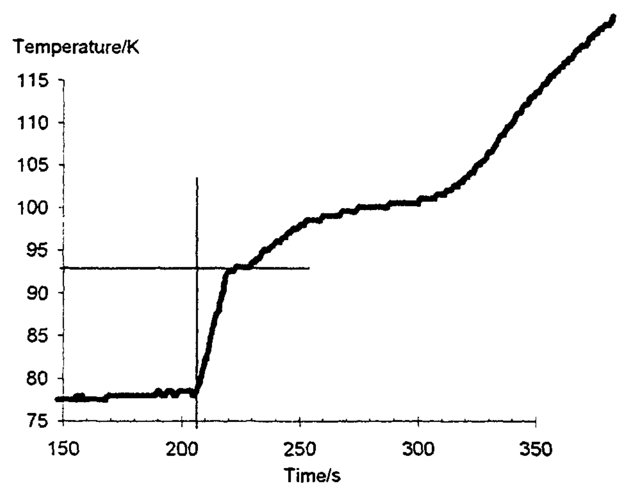

Fig. 13: Graph of thermocouple temperature vs. time in the Rounds-configuration experiment

3.3 Discussion

With the superconductor sample (and to a lesser extent the copper sample), the inflection in the weight loss curve corresponded to the sample starting to warm. A consequence of this (and presumably Rounds's original equipment[4] behaved similarly) is that any anomalies in the weight loss curve before the inflection point occur while the superconductor is at a constant 77K and are therefore most unlikely to be related to modification of gravitation.

Of more interest in the results is the slowing of warming rate at T_c which is reminiscent of a first order phase transition (like, for example, the melting of ice). However, the only first order phase transition reported in high T_c superconductors is flux vortex lattice melting and this has only been observed in small, high quality, flux grown single crystals, not in granular samples like ours[10]. Whilst this is an interesting observation and in need of further investigation, it appears to be a purely thermal effect without any implications for gravity research.

4. CONCLUSIONS

The conclusions from the present work are that the subset of the Podkletnov conditions examined here does not produce gravity modification measurable with our equipment (a resolution of the order of ±0.004%); it remains an open question whether gravity modification can be *repeatably* observed using the full set of Podkletnov conditions. This may, of course, only be a confirmation that not all of the correct and prescribed conditions have been achieved so far and that the present experiments could not be expected to show positive results.

The Rounds configuration also has not shown any effects unequivocally indicating gravity modification. Although some interesting effects have been produced, no effects reliably ascribable to gravity modification have been observed using either experimental arrangement.

From our repetition of the Rounds experiment, it appears likely that Rounds[4] was seeking a gravitational anomaly at an incorrect temperature. There was, however, unusual thermal behaviour in the YBCO results for which as yet there is no adequate explanation. Unusual behaviour around T_c has been found by other authors and it is known that high T_c superconductors with very short coherence lengths can show short-lived superconducting fluctuations up to 15K either side of T_c (the width of the distribution describing these fluctuations is proportional to coherence length). It is not clear that such fluctuations or thermal effects have any relation to any gravity effect.

4.1 Simplified summary of conclusions

Two recent experiments, one in Finland and the other in the U.S.A., have claimed to demonstrate reduction of the earth's gravity in a laboratory. Such observations are potentially of great importance to the future of spaceflight, air travel, and other endeavours in which gravity plays an important part. These experiments are extremely challenging technically and so an exact repetition is difficult; nevertheless, a partial repetition of the specified experimental conditions has been undertaken. No reduction in the earth's gravity has been observed by the present researchers to date. However, this may simply be because the full specified conditions have not yet been met.

5. FURTHER WORK

The next step in this work is to attempt a more complete test of the Podkletnov conditions. Work is already in hand to increase the disk size to 10cm diameter, to construct a magnetic levitation system, to construct rotation coils and to construct a disk braking system. Investigation of the detailed theory of such effects, in our view, should properly follow a repeatable demonstration of the Podkletnov observations beyond reasonable doubt.

6. ACKNOWLEDGEMENTS

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A PROPOSED EXPERIMENTAL ASSESSMENT OF A POSSIBLE PROPELLANTLESS PROPULSION SYSTEM

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Abstract. A proof-of-principal experiment is described for a possible propellantless propulsion system (PPS) concept presented during the Space Technology and Applications International Forum of 2001. A newly available, high power, solid state switch and recent improvements in superconducting magnets, may have made a propellantless propulsion system (PPS) possible. Propulsion may occur during the non-steady state condition of the ramp-up of a very rapidly pulsed, high power magnet. Propulsion would not occur after the first 100 nanoseconds of each pulse, since the magnetic field will have reached steady state. The switch can provide 100 nanosecond ramp-ups at a rate of 0.4 megahertz, and at 9,000 volts and 30 amperes. To produce an asymmetry in the magnetic field, a plate would need to be attached to one end of the magnet. The primary components of such a PPS would be an electrical power supply, the switch, and a low temperature, superconducting magnet, capable of 2,000 amperes per square millimeter. Other applications may include propulsion with significantly reduced thermal and acoustical signatures; and a means to dampen inertia.

Introduction

A proof-of-principal experiment is described for a possible propellantless propulsion system (PPS) concept presented during the Space Technology and Applications International Forum of 2001 (Goodwin, 2001). The effect under investigation for a possible propellantless propulsion system (PPS) is the movement of high power magnets, under certain conditions, during initial power ramp-ups. A newly available, high power, solid state switch, coupled with recent improvements in superconducting magnets, may have made possible a PPS based on this effect. This new concept could be termed "a solid state PPS".

If successful, this type of PPS would meet one of the NASA's Breakthrough Propulsion Physics (BPP) technical challenge #1 for "propulsion methods that eliminate ... the need for propellant"; and may meet BPP technical challenge #2 to "dramatically reduce transit times" (Millis, 2000).

Background

High power magnets are designed to avoid movements since such movements have detrimental effects on the experiments. When movements of the magnets are encountered, the magnets are redesigned to eliminate such movements (e.g., eliminate vibrations). By designing a system to exploit and enhance this Lenz's Law based movement, it may be possible to produce propulsion during the non-steady state conditions of the ramp-ups of very rapidly pulsed magnets.

The propulsion, if any, would only occur during the 100-nanosecond ramp-up of each pulse. After this ramp-up, the magnetic field will have reached steady state and no propulsion would occur. The non-steady, high power pulse might be producing an inertia drive effect, but without the need to mechanically move massive objects (which are limited by the strength of materials and produce only small amounts of propulsion, with supplied power; and, perhaps, no propulsion with on-board power). With sufficient power, it may be possible to accelerate the mass of the plate to 100s of g's.

The time for the magnetic field to reach steady state is related to the pulse duration (100 nanoseconds) and the size of the system (100 feet of wire). Given the size of the system (less than 1,000 feet), the magnetic field reaches steady state in less than 1 microsecond. This effect, if it exists, is different from magnetic "levitation" or Lenz's Law "jumping rings", both of which require the object to push off (or pull towards) other objects.

Until the recent improvements in technology, the motion produced by pulsed magnets has been an experimental interference. The motion is produced due to the Lenz's Law interaction of a pulsed magnet with an attached component producing an asymmetric magnet field. A large magnet for a particle physics moved about a centimeter every time the upgraded magnet was powered up, due to an attached component from a previous experiment. Since the component was no longer required, it was removed and the motion ceased. A small magnet for a fusion experiment moved several centimeters with the once per second pulses of 2,000 volts and 600 amperes. Since the attached asymmetric component could not be removed, the magnet was allowed to slide back into its original position. In this case, other interactions were discounted because the experiment was located in a laboratory with concrete block walls and with no rebar in the floor.

The form of Lenz's Law for a loop with fixed area is: $V = -A\ (dB/dt)$, where V is the voltage, A is the area of the plate, and B is the magnetic field. In addition to mass penalties and costs, increasing the magnetic field (B) is limited by the physical stresses on the magnet. Superconducting magnets can produce about 10 Tesla magnetic fields for years, but a 100 Tesla field destroys the magnet after about 500 pulses and a 500 Tesla field destroys the magnet after 1 pulse. There are substantial mass penalties and costs associated with increasing the area (A). The newly available switch allows more rapidly varying the magnetic field (dt) without significant mass penalties or costs. Modifying the waveform, by adding more switches and/or modifying the switches, could increase the pulses per second and reduce the size and mass of the system. Further system optimization would be to increase the amperage (superconducting magnets have been run at kiloamps); to modify the waveform of the switch (to provide more of the pulse in the ramp-up and less in the flat-top); and to reduce the size, mass, and complexity of the interfaces between the power supply and the switch and between the switch and the magnet (e.g., reducing the need for transformers and/or using superconducting transformers).

Concept

The primary components of such a PPS would consist of the switches; low temperature, superconducting magnets; and an electrical power supply.

In FY 2000, an IR-100 award was earned by Diversified Technologies of Bedford, MA (http://www.divtecs.com), for the development of a high power solid-state switch. The $6K, 7"X7"X3" switch can provide 100 nanosecond ramp-ups at a rate of 0.4 megahertz (MHz), and at 9,000 volts and 30 amperes. Allowing for the duty cycle of the ramp-ups and ramp-downs, the switch provides an integrated power of about 250 KWe. Compared to previous switches, the new switch is more compact, of lower mass, 10 times more energy efficient (only a 0.2% energy loss), and has 1000s of times higher reliability than vacuum tubes. Since the new switch has a pulse rate 10 times faster than previously available, the mass of the magnet can be reduced by a factor of 10.

Another recent improvement in technology which contributes to the possible enabling of a PPS, is a the low temperature superconductor that has recently become available which operates at 2,000 amperes per square millimeter; i.e., 10,000 times more than a non-superconductor (Barletta, 1999). High temperature superconductors carry 20 times less amperage and would probably not be able to tolerate the magnetic fields and/or the pulsed power.

To produce an asymmetry in the magnetic field for the Lenz's Law interaction, a plate would need to be attached to one end of the magnet. To prevent the energy from the pulse being carried away as induced current, the plate would need to be insulated during the ramp-ups. To prevent oscillations during the ramp-downs, the plate would to be uninsulated until the next ramp-up (by using a voltage-regulated switch with a timer to connect the plate to a drain during the flattop of the pulse and then disconnect the plate from the drain before the next ramp-up).

Experiment

The proof-of-principal laboratory experiment should initially use 1 switch, 1 magnet, and externally supplied power. The experiment could use the commercial-off-the-shelf (COTS) switch and a commercially available cable for the superconducting magnet. As with the designs for other types of experiments, the cryostats would need to be electromagnetically non-interacting.

Superconducting cable consists on up to 60 superconducting wires in a parallel conductor configuration. Allowing 500 nanoseconds during each power pulse to connect the plate to the drain, drain the plate, and reinsulate the plate, indicates about 2,000 feet of superconducting wire would be required for the propulsion magnet (to convert the electrical energy to propulsion in the remaining 2,000 nanoseconds of the power pulse). Reconfiguring 20 of the wires in the cable to be a series conductor would result in 100 feet of cable being required for the propulsion magnet. This configuration would convert each power pulse from the switch into 20 pulses of the magnet (8 MHz) and allow 20 passes through the magnet to convert each power pulse into propulsion, if the returns can be tuned to increase the ramp-up without producing a flat-top. Only about 5 KWe (2%) of the 250 KWe may be converted to propulsion since the ramp-up is only 4% of the duty cycle and the ramp-up starts at 0% power and increases to 100% rated power (i.e., averages 50% of rated power). As the ramp-up continues to build, the wires would be carrying 300 amperes (20 passes at 50% rated power). If a 2 g acceleration is produced, each pulse of the magnet would result, on average, in 0.6 milliwatt-seconds being converted into 1.2 microns of lateral motion on a supporting surface. With 32 windings and a 1-foot diameter, the magnet would have a height of about 3 feet. The cable would have a mass of about 25 kilograms. The magnet, with the cryostat, would have a mass of $\geq$ 50 kilograms (excluding the plate).

A holdup magnet (without a plate) would be required to allow the unused energy to be returned to the switch with the correct timing for the next power pulse. Reconfiguring the 60 wires in the cable into a series conductor would result in 40 feet of cable being required to return this 2,400 nanoseconds of the power pulse. The holdup magnet would be similar in size and mass to the propulsion magnet. The wires in holdup magnet would only be carrying 30 amperes.

PPS assessment criteria (Millis, 1997) include: "must ... induce a unidirectional acceleration ... be controllable ... sustainable ... be effective enough to propel the vehicle ... satisfy conservation of momentum (and) energy ...can be ... carried ... on the vehicle (and) consistent with empirical observations." (Millis, 1997).

Although the proposed PPS appears consistent with empirical observations and conservation of energy is not an issue, the following tests are required to confirm this and to determine if the other PPS criteria are met:

1. Confirm uni-directional motion (net external force) is produced (e.g., not limited to oscillations).

2. Confirm momentum is conserved without pushing off or pulling toward other objects (voltage regulated switch locked to drain should result in no motion; and locked to insulated mode should result in oscillations).

3. Confirm the system is effective enough to be carried on a vehicle and propel a vehicle (by measuring acceleration produced against power input). Given the potential for high energy efficiency, this type of PPS may be capable of producing near the theoretical maximum conversion of 20 kg/kWh for a 1 g thrust-per-power.

4. Confirm the system is sustainable (by long duration runs). The DOE Office of High Energy and Nuclear Physics is providing funds for the Alpha Magnetic Spectrometer (AMS) to be flown on the International Space Station. Most of the mass of this 7-ton detector is a superconducting magnet, which will operate for 3 years without maintenance. The magnet has 90 km of superconducting cable and an 800-watt cooling system.

Although the proposed PPS appears readily controllable, this could be confirmed by follow-on laboratory experiments with additional switches and magnets.

Demonstration

A sub-orbital demonstration vehicle would require an on-board electrical power supply, such as the 30 KWe "microturbine", commercially available from Capstone Turbine Corporation of Chatsworth, CA (http://www.capstoneturbine.com). Extensive modifications would be required for this COTS power supply.

To match the microturbine, 6 switches (@ 5 KWe) would be required to convert the 30 KWe into propulsion. By configuring all 60 wires of the propulsion magnet into 3 sets of 20 conductors in series, the same propulsion magnet (and holdup magnet) could be used from the above experiment, if the switches can be tuned to have their ramp-ups build and not produce a flattop. With 2 switches for each set of 20 conductors in series, the propulsion magnet would be carrying 600 amperes, whereas the holdup magnet would be carrying 180 amperes (from the 6 switches). Since the propulsion magnet would still be operating at 8 MHz, a 2 g acceleration (a net of 1 g over gravity) would result in each pulse of the magnet, on average, converting 3.6 milliwatt-seconds into 0.6 microns of vertical motion (for this more massive object moving against gravity).

Given the maximum conversion of energy to propulsion noted above (10 kg per KWH for a 2 g acceleration), the mass of the demonstration vehicle would need to be kept below about 300 kilograms (including about 2 kg of fuel/oxidizer per KWH). Test stand runups could initially be performed with air, and then with an on-board oxidizer (e.g., LOX).

Applications

Possible NASA missions for this type of PPS would include the manned mission to Mars and the interstellar "precursor" probe. If the solid state PPS can provide a continuous acceleration of up to 0.2 g, the transit times for robotic missions would be reduced from years to months and for manned missions from months to weeks. As discussed below, the mass of the reactors/PPS may be only about 20% of the vehicle mass for a 0.2 g acceleration.

For launches within gravitational wells, specific power (KWe/kg) is the critical factor (which requires chemical based power supplies). For transits through the solar system and beyond, specific energy (KWH/kg) is the critical factor (which requires nuclear based power supplies). A space-based reactor with a specific mass of $\leq$ 18 kilograms per KWe and a conversion efficiency of $\leq$ 30% can be available with existing technology in 5 years for units with $\leq$ 0.3 MWe and 10 years for units of $\geq$ 1 MWe (Houts 2001, Lenard 2001, Lipinski 2001, Polk 2001, and Poston 2001).

The solid state PPS, with about a 0.1 MWe reactor, should be suitable for most robotic missions. For example, this sized system would provide more payload, power, and data return capability for such missions as the (precursor) "interstellar probe" to the heliopause at about 200 AU and on into the interstellar medium to about 400 AU (Liewer, 2000). Using the maximum conversion efficiency noted above (100 kg per 0.2 g acceleration), 90 KWe may result in a vehicle mass of up to 9 tons (what a Delta IV heavy can take to an escape orbit) and would use an optimized propulsion magnet. To match the 90 KWe, would require 18 switches (@ 5 KWe), with 6 switches connected to each of the 20 conductors in series, if the switches can be tuned to produce ramp-ups and not a flat-top. The wires in the propulsion magnet would be carrying 1,800 amperes and the wires in the holdup magnet would be carrying 540 amperes. The size and mass of the magnets would be the same as for the experiment and the demonstration. Since the propulsion magnet would still be operating at 8 MHz, a 0.2 g acceleration, would result in each pulse of the magnet, on average, converting 11 milliwatt-seconds into 0.1 microns of motion (for this much more massive object). Scaling from the AMS magnet, $\geq$ 10 watts of cooling would be required for each magnet.

At the maximum conversion efficiency, the solid state PPS, with a 1 MWe power supply, may be able to propel a 100-ton, manned vehicle at 0.2 g for manned missions within the solar system. Reactors can be placed in Earth orbit in a non-critical configuration. All subsequent departures and returns could be to the lunar polar orbit which faces the maximum distance away from the Earth. For launches to and returns from LEO and the polar lunar orbit, the same type of vehicle could be used, except with a chemical based electrical power supply. With the maximum conversion energy to propulsion and fuel/oxidizer consumption per KWH noted above, a vehicle to LEO would require at least 7% of the vehicle mass for fuel/oxidizer. The solid state PPS may also be able to provide substantial maneuver capability for manned and unmanned vehicles. Providing an acceleration of 0.4 g (increasing the mass of the reactors/PPS to 40% of the vehicle mass), would allow for nuclear powered landers for Mars and most moons.

To convert 1 MWe into propulsion would require 200 switches (@ 5 KWe); i.e., 11 or 12 of the 90 KWe (optimized) propulsion magnets. For the propulsion magnets, the rep rate (8 MHz), size, mass, power conversion per pulse, motion, cooling, and amperes would be the same as described above for the robotic missions. Three holdup magnets would be required (each operating at 2,000 amperes), and with the same size, mass, and cooling as described above.

The NASA BPP interest in PPS is because the potential ISP is in the billions of seconds, as compared to $\leq$ 480 seconds for rockets and $\leq$ 5,000 seconds for ion drives.

The solid state PPS may be able to provide:

1. Substantially reduced thermal signatures for aerospace craft and substantially reduced acoustical signatures for military and commercial aircraft, surface ("electric") ships and submarines (for the protection of the astronauts and the ISS, the AMS magnetic is being designed to minimize stray electromagnetic fields).

2. Cost-effective boost and maneuver for trans-atmospheric vehicles and for orbital vehicles to transfer from one orbit to another (possibly including real time, varying adjustments over each ISS orbit).

3. Commercial supersonic flight.

4. Significantly reduced vibrations and acceleration/deceleration from launch/deorbit.

5. Elimination of the need for tiles.

6. Powered landings.

7. The additional safety of twin engines, either of which may be able to return the vehicle (with a lifting body fuselage for additional safety inside the atmosphere).

With this type of propulsion system, it might be possible to dampen inertia. Using < 20 femtosecond pulses, a 10 g acceleration could be divided into 0.01 angstrom increments, which may allow the biological cells time to recover from each short burst of acceleration. This approach should lend itself to microfabrication. For example, using a 1 megahertz switch (under development by the vendor)), an integrated circuit with 50 million micromagnets would be required to convert 5 KWe to propulsion without inertia. Each micromagnet would have about 5 microns of wire to convert 0.1 nanowatt-seconds per pulse into propulsion. Since the micromagnets would be in series, they would need to fail closed. Since 10 square microns of wire are required for each unit, 10 micromagnets in parallel in each unit would allow the micromagnets to fail closed. By more rapidly varying the magnetic field, such a system may also increase the conversion efficiency of electrical energy to propulsion. The cooling requirements may also be reduced.

Summary/Conclusions

By using very rapidly pulsed magnets, it may be possible to develop a propulsion system that does not rely on propellants. If successful, such a system would substantially reduce the cost of the spacecraft and would reduce the transit times for robotic missions from year to months and for manned missions from months to weeks.

Acknowledgments

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THE ELECTROMAGNETIC STRESS-TENSOR AS A POSSIBLE SPACE DRIVE PROPULSION CONCEPT

by

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ABSTRACT

The Heaviside force, by virtue of its nonzero value in vacuum, would appear to offer the germ of a real space-drive. Classical electrodynamic interactions may be viewed as transmitted continuously through deformations in the state of the electromagnetic field, which acts like a stressed elastic medium. Maxwell stresses not only provide a controllable net momentum flow, but also a physical mechanism acting on the fabric of space-time. In response to this unbalanced force it has been asserted that a spacecraft will move off with equal and opposite momentum. The electromagnetic interaction mechanism under consideration suggests the basis for a novel development in electrical machine technology and a possible space-drive for space transportation. The physical basis of this concept is examined in this paper, and experimental investigations are described. Supporting analyses and historical background are included.

INTRODUCTION

Perhaps the most intriguing challenge facing twenty-first century space-flight is the novel concept of a "Space-Drive".[1] John W. Campbell[2] and Sir Arthur C. Clarke[3] are usually credited with conceiving this visionary hypothesis. Without proposing any physical mechanism (for which one might cultivate some emerging technology to exploit) they articulated what such an astonishing apparatus will do: *a space-drive is a propulsion mechanism that acts directly upon the fabric of free-space.* (Actually, the notion of a space-drive was discussed in the engineering literature almost a dozen years earlier by Joseph Slepian. See below.) Remarkably, spacecraft employing such space-drive devices would not have to convey any reaction mass to eject as propellant.

The grand challenge is, how might such a striking proposition be supported within the framework of conventional physics? And, even more thought-provoking, how might such a concept be realized in actual engineering hardware? There exist several enchanting candidates for making progress along these lines. We will address only one such concept, and let us confess from the offset that we have no startling breakthrough to disclose. However, we do want to report on a phenomenological approach to the problem, which, to us, would seem both to encompass the concept of a space-drive, and also to hold out the promise of achievability with technology that is within reach.

ELECTROMAGNETIC FOUNDATION

In Maxwell's field theory electrodynamic interactions are transmitted continuously through deformations in the state of electromagnetic fields, which act like elastic stresses. (Note that Maxwell's equations were already relativistically covariant when he wrote them down in 1864, so what we are exploring has little, if any, relation to the old "luminiferous aether" theories.) Recall that in General Relativity (also a field theory) the interactions are transmitted as deformations in the underlying metrical structure of space-time. Ultimately, any true space drive mechanism must be expressible within such a framework. The *original* force-field derivation, actually constructed by Maxwell[4] (and extended to vector differential form by Heaviside)[5,6] provides the archetypical classical space-drive: an electromagnetic force acting directly upon the electrical fabric of space-time itself. The classical derivation of the Maxwell stress tensor is presented in many places and we have discussed it in several previous publications.[7,8]

The most direct approach for developing the stress tensor is to start with the traditional coordinate independent Gibbsian, vector differential form of Maxwell's four celebrated equations in practical engineering (MKSA) units:

$$\nabla \bullet \vec{D} = \rho \tag{1}$$

$$\nabla \bullet \vec{B} = 0 \tag{2}$$

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \tag{3}$$

$$\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t} \tag{4}$$

where ρ is the free electric charge density and **J** is the sum of the electric conduction (σ**E**) and convection (ρv) current densities. The stress tensor is quadratic in the fields and is erected by formally crossing Ampere's law into the magnetic induction vector, **B**, and Faraday's law into the electric displacement vector, **D**, and adding Gauss' laws (both electric and magnetic) multiplied by the field strengths **E** and **H**, respectively, to obtain the expression

$$\nabla \bullet \vec{T} = \rho \vec{\mathbf{E}} + \vec{\mathbf{J}} \times \vec{\mathbf{B}} + \frac{\partial\,(\vec{\mathbf{D}} \times \vec{\mathbf{B}})}{\partial\,\mathrm{t}} \tag{5}$$

where $\overleftrightarrow{T}$ is the classical Maxwell stress tensor, and may be expressed by

$$\vec{T} = \vec{E}\,\vec{D} + \vec{H}\,\vec{B} - \frac{1}{2}\left(\vec{E} \bullet \vec{D} + \vec{H} \bullet \vec{B}\right)\vec{I} \tag{6}$$

in the common dyadic notation of Gibbs. (The product of two vectors is a dyadic quantity and **I** is the unit dyadic.) For practical calculations one usually writes down the covariant or contravariant components of the tensor in some desired system of coordinates. For example, the components of the coordinate independent tensor quantity may be expressed on the tangent basis vectors, $\mathbf{e}_\mu$, or on the dual basis covectors, ϖ^ν, of some particular system of coordinates through

$$\vec{T} = T^{\mu\nu}\,\vec{e}_\mu \otimes \vec{e}_\nu = T_{\mu\nu}\,\varpi^\mu \otimes \varpi^\nu \tag{7}$$

where $\langle \mathbf{e}_\mu, \varpi^\nu \rangle = \delta_\mu^{\ \nu}$ expresses the dual nature of the basis. The covariant *components* of the Maxwell stress tensor are given by

$$T_{\mu\nu} = h_\mu h_\nu (E_\mu D_\nu + H_\mu B_\nu - \delta_{\mu\nu} W) \tag{8}$$

and the contravariant *components* of the tensor are given by

$$T^{\mu\nu} = \frac{1}{h_\mu h_\nu}\left(E^\mu D^\nu + H^\mu B^\nu - \delta^{\mu\nu} W\right) \tag{9}$$

where $\mu,\nu = 1, 2, 3$ and $W = \frac{1}{2}(\mathbf{E}\bullet\mathbf{D} + \mathbf{H}\bullet\mathbf{B})$. In orthogonal curvilinear coordinates, the metrical line element is expressed as

$$ds^2 = \left(h_1 dx^1\right)^2 + \left(h_2 dx^2\right)^2 + \left(h_3 dx^3\right)^2 \tag{10}$$

with coordinate "scale factors" h_μ. [We note in passing that Maxwell's equations, and the stress tensor, $\overleftrightarrow{T}$ itself, are independent of any metrical relation either Riemannian or conformal. Not only is a metric tensor not needed for writing down Maxwell's equations, but also no connection, neither Riemannian nor projective nor conformal, is required. Van Dantzig[9,10] has shown that, in spite of this fact, the *divergence* of the four-dimensional stress energy-momentum tensor, which gives the Lorentz force density as well as the Poynting theorem, *cannot* be formulated without the aid of a metric.]

The divergence of the stress tensor, Equation (5), has the units of N/m^3, a force density, and, therefore, implies momentum transfer. How is this to be understood? The equation actually indicates that the classical electromagnetic force expressions (the Coulomb force and the Lorentz force) are, in fact, inherent in Maxwell's equations. Since the last term on the right does not vanish in empty space it further suggests the idea of a volume force on vacuum or, at least, on the permeability, μ_o, and permittivity, ε_o, of free-space by means of vacuum displacement current interaction. Note that since $\overleftrightarrow{T}$ contains only field terms, $\nabla \bullet \overleftrightarrow{T}$ is a force exerted by the fields.

FIELD MOMENTUM

If one volume integrates both sides of Equation (5), one obtains

$$\vec{F} = \iiint_V \left(\rho\,\vec{E} + \vec{J} \times \vec{B}\right) dV + \iiint_V \frac{\partial \vec{g}}{\partial t}\,dV \tag{11}$$

which has the units of newtons, where we have set

$$\vec{g} = \vec{D} \times \vec{B}\,. \tag{12}$$

In Equation (11), the first two terms on the right are the familiar forces on charges and currents.

However, a third force mechanism has emerged which is not zero in empty space:

$$\bar{F} = \iiint_V \frac{\partial \bar{g}}{\partial t} dV \ . \qquad \textbf{(13)}$$

Concerning this curious term, Abraham and Becker have observed, *"The remarkable thing about this force is that its existence does not presuppose the presence of matter, the Maxwellian stresses provide a 'moving' force at points of empty space, even though there is no matter there for the force to move."*[11]

Recognizing that force is the time rate of change of momentum, Heaviside identified $\mathbf{g} = \mathbf{D}\times\mathbf{B}$ as the electromagnetic field *momentum density* more than one hundred years ago. With the advent of the Special Theory of Relativity, Hermann Minkowski incorporated the notion of field momentum into a four-dimensional formulation of the Maxwell stress tensor. (See Appendix I, below.) Since then, a variety of expressions have appeared for the electromagnetic field momentum, and until recently, with the measurements of Graham and Lahoz, there existed no experimental evidence to resolve the issue as to which expression is physically correct.

There is another interesting feature associated with the electromagnetic momentum. It has been observed that mechanical momentum is *not* conserved by itself alone, and that action is equal to reaction only when *both* mechanical and electromagnetic momenta are considered. It is the total (mechanical plus electromagnetic) momentum (both angular and linear) that is conserved. Action and reaction forces are always equal in magnitude and opposite in direction, and Newton's third law is satisfied - but only if electromagnetic momentum is included and correctly accounted for. O'Leary[12] gives an example of such a calculation.

Oddly, this third term appears to be *precisely what is desired* for a true "Space-Drive", and its manipulation is of engineering interest. In fact, the phenomenon seems to have first been suggested as a possible electromagnetic space-drive concept as early as 1949.

SLEPIAN AND THE SPACE DRIVE

In one of his many "Electrical Essays for Recreation", Dr. Joseph Slepian, of the Westinghouse Research Laboratories in Pittsburgh, hypothesized an electromagnetic space-ship propelled by RF forces on vacuum.[13] (Though related, this is not radiation pressure.) His 1949 essay clearly illustrates the notion of what has since come to be known as a "Space-Drive": the craft was to be propelled, in Slepian's words, by *"a means of propulsion which does not require any material medium upon which the propelling thrust is exerted"*, and, as such, the structure might be thought to be appropriate for use in space.

The mechanism that Slepian described was, essentially, a parallel plate, conformally mapped version of what later became the Graham-Lahoz cylindrical capacitor experiment.[14] For his conceptual arrangement, Slepian concludes that the structure really does experience an unbalanced linear force – but for the arrangement given (**E,H** sinusoidal; stationary volume of interaction) the force is an alternating one, with zero time-average.

LINEAR FARADAY DISK MACHINE

In modern notation, what Heaviside actually wrote in 1886 was that the force to be accounted for by a state of stress in the fields is

$$\bar{\mathbf{f}} = \rho\bar{\mathbf{E}} + \left(\bar{\mathbf{J}} + \frac{\partial \bar{\mathbf{D}}}{\partial t}\right)\times\bar{\mathbf{B}} \ + \ \bar{\mathbf{D}}\times\frac{\partial \bar{\mathbf{B}}}{\partial t} \qquad \textbf{(14)}$$

The electric current (convection plus conduction) and displacement current are given by

$$\begin{aligned} \bar{J} &= \rho\bar{v} + \sigma\bar{E} \\ \bar{J}_D &= \frac{\partial \bar{D}}{\partial t} = \varepsilon_0 \frac{\partial \bar{E}}{\partial t} + \frac{\partial \bar{P}}{\partial t} \end{aligned} \qquad \textbf{(15a,b)}$$

where, in linear media

$$\bar{D} = \varepsilon_0 \bar{E} + \bar{P} = \varepsilon_r \varepsilon_0 \bar{E} \ . \qquad \textbf{(16)}$$

Equation (5) is obtained by combining the last two product terms of Equation (14) according to the product rule for differentiation.

The classic Faraday homopolar machine is a simple geometry for obtaining rotary motion by exploiting the conduction current **J×B** force. The structure may also be arranged in the form of a linear pump for conducting fluids (as patented by Einstein and Szilard in 1928), or as a linear motor by making the conductor stationary and permitting the electric current source and magnet to translate. Alternatively, Wood[15] has proposed a novel neutral media accelerator by utilizing the polarization current $(\partial \bar{P}/\partial t)$ component of the displacement current in a crossed magnetic field: $\mathbf{J_P}\times\mathbf{B}$. Further, Slepian, in his space-drive system, proposed using the displacement current and the $\mathbf{J_D}\times\mathbf{B}$ force for propulsion. A machine based on these mechanisms might look something like that in Figure 1. In the limit, as $\varepsilon_r \to 1$, we have Slepian's space-drive.

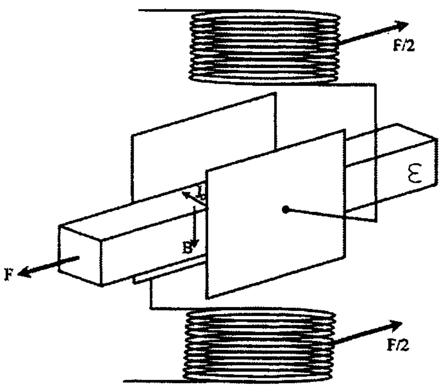

Figure 1. A dielectric linear motor. Crossed magnetic fields and displacement currents account for the propulsion.

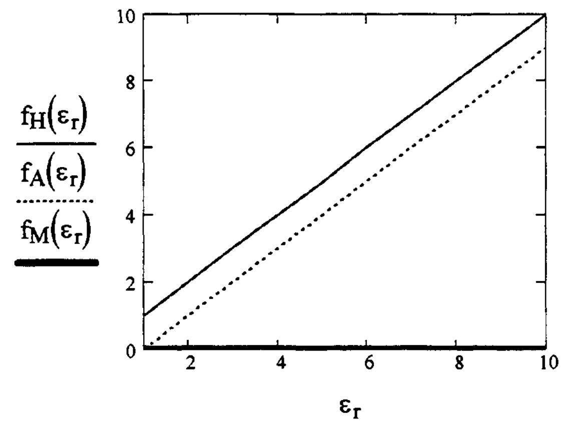

Figure 2. Force density in an insulator as a function of relative permittivity for Heaviside, Abraham and Minkowski.

GRAHAM-LAHOZ

What is the correct form for the electromagnetic force density in material media? What expression is the true representation for the electromagnetic field momentum in matter? Is it possible for static electric and magnetic fields from different sources to combine to provide field momentum (angular or linear) in vacuum? In an attempt to resolve these thorny issues Walker, Graham and Lahoz have carried out a number of experimental investigations. Their results would seem to support the conclusion that the field force density does not approach zero as $\varepsilon_r \to 1$. As part of the ISR BPP research project, we have subcontracted the Physics Department at West Virginia University to re-examine these basic experiments. (See Appendix III, below.)

Graham, Lahoz, and Walker have asserted that their experiments not only verify the reality of electromagnetic field angular momentum in vacuum for quasi-static fields,[16] but surprisingly, they have determined that both the Minkowski and the Abraham stress tensor formulations predict results incommensurate with experimental observations.[17, 18] (See Table I, which summarizes their results.)

HARTLEY/MANLEY-ROWE

Slepian concluded that the field force is, indeed substantial, but that it is an alternating one with zero time-average. The inherent presupposition in Slepian's work was that his field system possessed stationary boundary conditions. This assumption was first delineated by H.A. Lorentz. (See Appendix II.) The issue is, how does one spectrally translate an oscillating force to have a DC component? We have discovered among the works of R.V.L. Hartley (of Hartley oscillator fame), published while he was at the Bell Laboratories, a remarkable phenomenon for accomplishing just this.

In the course of Hartley's work on nonlinear and time varying reactive modulators, he observed the peculiar artifact of a mechanical DC offset in the equilibrium position of the plates of an AC excited capacitor where no DC fields were applied.[19] Also, there were no conventional means of rectification present to provide such DC offsets. This work, which started in 1917, led to several publications through the 1920's and 1930's and culminated in the Manley-Rowe[20,21] papers in 1956. They conclude that time-varying and nonlinear elements both result in spectral translation. (Linear time-invariant systems never produce new frequency components.)

Setting up the Hartley criteria in Slepian's conceptual spacecraft results in nonstationary boundary conditions and a unidirectional force, as shown in Figure 3. (This should be of interest to others attempting to create a space drive out of alternating forces. Perhaps this can be adapted for use with coherent zero-point fluctuations.)

INSTANTANEOUS RADIATION PRESSURE

While the momentum of the radiation field and the phenomenon of radiation pressure emerge naturally from the Maxwell stress tensor, it should be noted that radiation pressure is somewhat different from

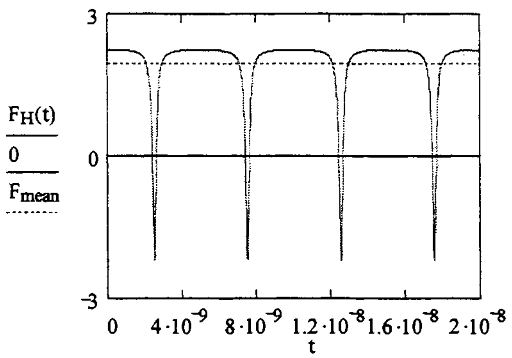

Figure 3. Volume integrated Heaviside force in a nonstationary medium as a function of time.

the field force exploited by Slepian in his uniform field coil-capacitor resonator. In Slepian's resonator, the orthogonal **E** and **H** fields are actually in time quadrature. (True radiation fields are in-phase, of course.) As a result, Slepian's fields produced a huge instantaneous force, but one with zero average value. However, as we have just discussed, the Hartley/Manley-Rowe boundary variations will provide Slepian with a spectrally translated longitudinal DC force. (See Appendix II.)

We also need to mention that most pedagogical treatments of radiation pressure present only the time-average value of the pressure of the incident radiation field at the interface. It should be noted from Appendix I that each distinct formulation of the Maxwell stress tensor predicts a different *instantaneous* radiation pressure. The instantaneous Minkowski, Abraham, and Maxwell-Heaviside radiation pressures are plotted in Figure 4 for a slightly lossy interface.

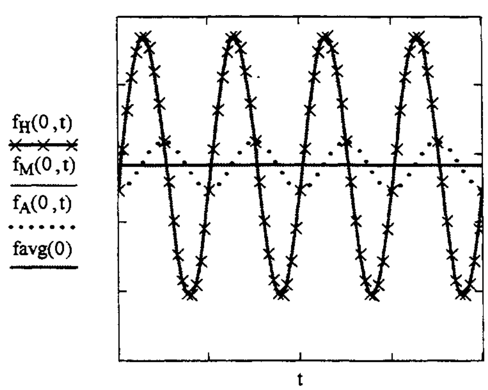

Figure 4. Instantaneous radiation pressure for the Heaviside, Minkowski, and Abraham tensors.

EXPERIMENTAL PROGRAM

Approach

In studying the linearization of the Faraday Disk machine, in both its **J**×**B** and $\mathbf{J_D}$×**B** [as defined in Equation (15)] configurations, a way of implementing it in a laboratory environment was sought. It became obvious that one of the constraints was that there was always going to be some **J**×**B** component in the $\mathbf{J_D}$×**B** apparatus, and that a way of separating out the two components would be required. This would be done by making force measurements with a **J** the same length as the metallic conductor portions of the $\mathbf{J_D}$ experiment and seeing if the force were greater when the $\mathbf{J_D}$ length was added. After searching through the early literature on **J**×**B** experiments, we came across the work of Andre Marie Ampere and Hypolyte Pixii in what has become known as Ampere's Rail Motor. In modified form it is now known as the Rail Gun. The very first version of this apparatus consisted of troughs of mercury on which floated a bridge made from iron wire. When a DC current was passed through the mercury and iron wire, the bridge was found to float away from the source of DC current. Later versions replaced the mercury by metal rails and the iron bridge with two wheels connected by an axle. Either grooves in the rail prevented the wheels from rolling off, or classical railroad wheels with inner flanges were used to prevent the wheels from rolling off. What we found curious was that, invariably, in almost all reference books the experiment is never attributed to Ampere (or anyone else for that matter). Further, the magnetic field is always provided independent from the current flowing through the system, unlike in the original experiment where the **J** current also generated the **B**-field. And finally, the Ampere's Rail Motor *is actually a Universal Motor*: it provides a unidirectional force with both DC and AC excitation – a phenomenon which we demonstrated recently. (Strangely, we have not been able to find any references in the literature to this behavior.) Apparently, we are the first group to demonstrate this. Even the rail gun community always use pulsed DC. It was because of the capability of the Ampere-Pixii Rail Motor to operate as a universal motor that we chose to continue with that experimental configuration through the first phase of our experimental program.

Phase I

In order to use the Ampere-Pixii apparatus to demonstrate the possible unidirectional or oscillating force on a dielectric from the $\mathbf{J_D}$×**B** component of the Heaviside formulation of the Maxwell stress tensor, we would have to make a break in the circuit (as was

TABLE 1. EXPERIMENTAL RESULTS

Year	Medium	Observation	Conclusion
1975	**Matter**	$f \neq 0$	**Minkowski** Wrong
1976	**Matter**	$f \neq \frac{(\varepsilon_r \mu_r - 1)}{c^2} \frac{\partial (\mathbf{E} \times \mathbf{H})}{\partial t}$	**Abraham** Wrong
1980	**Vacuum**	$f \approx \frac{1}{c^2} \frac{\partial (\mathbf{E} \times \mathbf{H})}{\partial t}$	Correct

done in the Slepian configuration) and insert a capacitor. We decided to insert the capacitor in place of the axle between the wheels, which would make the displacement current generate the force that caused the wheels to roll away from the power generator. Discussions with several manufacturers of capacitors revealed that the largest two-plate capacitor we could obtain was only 20,000 pF, utilizing a dielectric constant of approximately 5000; we also obtained two-plate capacitor discs with dielectrics from about 1000 down to 10. In order to obtain a current of close to 50 amperes flowing through the capacitor (this was the current required with a metallic conducting axle to get the wheels to roll consistently), we could not use 60 Hz AC; based on commercially available components and our budget constraints, we chose 30 kHz as the frequency at which we would run this first experiment. The self-field at 50 amperes was only a couple of gauss for the **B**-field, so we also built a set of 30 kHz Helmholtz coils, which would provide a factor of between 20 and 40 improvement in the **B**-field (50-100 gauss, depending on the circuit Q). The phasing between the capacitor current and the Helmholtz coil current can be varied continuously over a wide range with a specially designed and constructed phasing network. Several series resonating inductors of various values to resonate the capacitor-axles at 30 kHz have been built. It is assumed that the force may be oscillating, notwithstanding the Universal motor characteristics, so a piezoelectric transducer will be used to measure the magnitude of the oscillating force. Should the Universal motor characteristic provide a unidirectional force at 30 kHz, we will be quite pleased, to say the least.

The DC power supplies are based on autotransformers followed by full wave rectifiers and capacitor filters. (The parts are refurbished components that were once used in the coal mining industry here in West Virginia.) These power supplies will be used to drive the Class D amplifiers/power generators.

The two 30 kHz power generators are based on a full H-bridge, Class D amplifier topology. We are using Insulated Gate Bipolar Transistors (IGBT's) from IXYS Corp. for the H-bridge final drive devices, and are utilizing International Rectifier's driver chips to simplify the overall circuit. The IGBT's are rated for 1200V @ 150A, though our DC power supply is limited to 300V @ 150A, so we will not be subjecting them to their full voltage stress. The design can be easily expanded through the use of multiple devices to handle up to 900A at the same 1200V. We have also mocked up the amplifiers using IXYS BIMOS transistors, which, though they are only rated at 1200V @ 60A, are capable of operation up to several hundred kHz, as opposed to the IGBT's limit of 30-40 kHz.

The Helmholtz coils employed in our research are unique. They are a modified *spiral* coil design, instead of the classical solenoid or multi-turn loop. The reason we chose the spiral coil was that it required less wire for the same number of ampere-turns, and we got a higher field strength with the same length of wire as compared to a solenoid, as determined from our electromagnetic modeling software. The overall height of the spiral coil system is smaller than a solenoidal system. And, with some modifications to the inner turns, we were able to obtain the same field uniformity as with the classical Helmholtz coil. Laboratory measurements confirmed this. With uncompensated spirals, the magnetic field distribution was sharply peaked in the center.

The reason we want to make the tests with several different dielectrics is to establish whether, when the force is plotted versus dielectric constant, it intersects at zero or if it intersects above zero on the force axis. (See Figure 2, above.) This will determine if the force is nonzero when the dielectric is vacuum (dielectric equal to 1). We have not been able to find any commercially available parallel plate vacuum capacitors with capacitances greater than 100 pF with plate spacing's greater than a few millimeters, which is too small at the frequency and current levels that we can obtain at the present time. Therefore, we are taking the indirect approach of measuring forces for dielectrics approaching 1 and finding out what the intercept is. As a point of note, the Graham-Lahoz experiments showed that the intercept is above zero on the force axis for angular momentum; we are expecting to be able to demonstrate the same intercept bias for linear momentum.

As a backup to this experiment, in case we run into unforeseen problems, we have a pulsed experiment, using a large permanent magnet for the **B**-field, and a stack of disc capacitors that will be configured as a Marx bank. Everything will be held stationary during the parallel charging of the bank; then the stops will be released and the discharge of the bank in series will generate a large current, which coupled with the 10× larger **B**-field (~1000 gauss) will result in a several orders of magnitude larger force. Because this is the equivalent of a quarter sine wave, the force will be unidirectional. The reason we are performing the rail experiment first is that the short time constant (microseconds) of the larger force will be difficult to observe because of the greatly increased mass of the second experiment (several hundred kilograms) to that of the first (a few kilograms) compared to the magnitude and duration of the force (newtons for microseconds versus millinewtons for seconds)

Phase II

The second phase of our experimental program will be to 'rectify' the force. This experiment will utilize the Hartley-Peterson-Manley-Rowe effect to perform the rectification as described earlier. Because of the requirement to operate the electronics to wobble the capacitor plate at twice the drive frequency, it will be a challenge to obtain commercially available components with these capabilities at the high power levels required to measure a detectable force (several 10's of kilowatts minimum). We also want to operate the apparatus first at the 30 kHz for which we already have several high power generators; then at between 10 and 30 MHz, which will require us to build new amplifiers. It has been our experience that the Class D topology is no longer feasible at frequencies above about 5MHz, so we will be utilizing the Class E topology. As with Class D, this also offers very high efficiency (>90%), as well as some ruggedness to impedance mismatches, though we will be protecting the generator from high reflected power by using lumped element hybrid couplers in a back-to-back configuration, resulting in an economical circulator. The usual method of protecting RF equipment from high-reflected power is to use a circulator/isolator, but these Faraday rotation devices are not commercially available for frequencies much below 70 MHz. The dual hybrid coupler can be built or purchased for any frequency from 60 Hz to low GHz frequencies and for power levels from mW to MW. We are utilizing this lumped element coupler technique in connection with other ongoing research efforts.

CONCLUSIONS

The goal of finding an appropriate physical phenomenon to exploit and actually creating a true space-drive is a tall order. Assuming that such a device is possible, where will it be found? A variety of strategies may be employed to discover this elusive mechanism. It may be searched for along the frontiers of modern science, it may be sought in the risky hinterlands of unconventional physics, or looked for among the foundation stones of conventional knowledge. This paper reports on research along the latter path.

We have taken the position that electromagnetic forces follow directly from Maxwell's equations and, consequently, that the Heaviside force is worth experimentally studying. If the Heaviside hypothesis is correct, then, indeed, a phenomenology exists as the basis of a true space drive. While the forces might (initially) seem small, an emerging technology may then be cultivated to exploit this phenomenon. If the Heaviside hypothesis should prove to be in error, then the payoff for this research is the experimental delineation between the various classical formulations of the Maxwell stress tensor and electromagnetic momentum.

In conclusion, the appropriateness of our research effort may be measured against the five "Tests for Breakthrough Propulsion Physics." (1) Is the candidate research 'Grand'? (That is, does it possess the *potential* to respond to the 'Grand Challenge' of a true space-drive?) (2) Is the research aimed at a real 'Breakthrough'? (It must be something more than merely a refinement of conventional practice.) (3) Is the candidate research 'Credible'? (It must be scientifically sound and not what Irving Langmuir once called 'Pathological Science'.) (4) Is the research 'Measurable'? (Can quantifiable advances be identified?) (5) 'Near Term'? (Incremental progress must be inherently possible in the concept under investigation.) We believe that, when measured against each of these criteria, the answer is 'yes', and the present research is certainly justifiable.

SUMMARY

A space-drive advance is being sought within the domain of conventional theory. It is our hypothesis that there exists within classical electrodynamics the germ of a mechanism which may be engineered into a method of propulsion not requiring the expulsion of reaction mass. Inspired by the original electromagnetic momentum concept of Oliver Heaviside, the relativistic field formulations of Hermann Minkowski and Max Abraham, and the nonstationary networks of R.V.L. Hartley, the BPP group at ISR is attempting to exploit a modified space propulsion arrangement due to Joseph Slepian. Heaviside formulated the electromagnetic field momentum notion within the framework of Maxwell's equations. Minkowski, Abraham, and others created four-dimensional versions of the stress tensor incorporating the field momentum concept. And, Slepian conceived the modern notion of an electrical space-drive: an electromagnetic propulsion mechanism acting directly upon space. However, Slepian only disclosed a propulsion configuration for which the space-drive delivered an alternating longitudinal force with zero average value. By incorporating the varying parameter systems of Hartley, Manley, and Rowe, one is quickly led to a Slepian-like space-drive that delivers a nonzero average force for rectilinear propulsion.

The theoretical basis has been explored, analytical models have been examined, and computer simulations have been carried out. However, the ultimate validation of the concept can only be determined experimentally in the laboratory. Such an investigation is currently being conducted.

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APPENDIX I. OTHER FORMULATIONS

In the present paper, we have attempted to discuss the Maxwell stress tensor within the framework of conventional vector analysis. The whole formulation may be expressed more elegantly by employing either Cartan forms or tensor components in a four dimensional space-time manifold. We will follow the traditional path. There are also several ways to formulate the four dimensional stress-energy momentum tensor in material media, and each has significant differences and consequences.[22] The most commonly discussed are the treatments by Minkowski,[23,24] Abraham,[25] Einstein and Laub,[26,27] and what is called the Amperian[28] (or Chu) formulation. While the features are different, all follow the prescription discovered by Minkowski in 1910.

Minkowski first assumed that Maxwell's equations were valid in a frame of reference in which the material media may undergo deformation and translation. Second, he assumed that the divergence of the three-dimensional stress tensor is as obtained directly from Maxwell's equations in Equation (5), above. Then, (and this is a critical step) by *calling* the sum of $\rho\mathbf{E}$ plus $\mathbf{J}\times\mathbf{B}$ the total force, i.e. by christening the Lorentz force density

$$\bar{f}_L = \rho\,\bar{E} + \bar{J}\times\bar{B}, \qquad \textbf{(A.I.1)}$$

as the total force, Minkowski was able to manipulate Equation (5) into the expression

$$\bar{f}_L = \nabla\bullet\bar{T} - \frac{\partial(\bar{D}\times\bar{B})}{\partial t} \qquad \textbf{(A.I.2)}$$

where the divergence is a three dimensional spatial operation. The form of Equation (A.I.2) inspires the introduction of a four-divergence operator. By combining Equation (A.I.2) with Poynting's Theorem in the form

$$\bar{E}\bullet\bar{J} = -\nabla\bullet\bar{S} - \frac{\partial W}{\partial t} \qquad \textbf{(A.I.3)}$$

(where $\mathbf{S} = \mathbf{E}\times\mathbf{H}$), Minkowski was able to obtain a sixteen-component, four dimensional tensor, $T_{\mu\nu}$, that may be represented schematically as

$$T_{\mu\nu} = \begin{bmatrix} \bar{T} & -\bar{g} \\ -\bar{S} & -W \end{bmatrix}. \qquad \textbf{(A.I.4)}$$

The four-divergence of his tensor is a four-vector whose three spatial components present the Lorentz force density (the force on charges and currents), as it was designed to, and whose fourth component gives the power dissipated per unit volume:

$$f_\mu = \nabla^\nu T_{\mu\nu} = (\rho\,\bar{E} + \bar{J}\times\bar{B};\ \bar{E}\cdot\bar{J}). \qquad \text{(A.I.5)}$$

Where the various prominent formulations differ is in their choice of an expression for the electromagnetic field momentum density, g. Minkowski chose

$$\bar{g} = \bar{D}\times\bar{B} \qquad \text{(A.I.6)}$$

while Abraham chose

$$\bar{g} = \frac{\bar{E}\times\bar{H}}{c^2} \qquad \text{(A.I.7)}$$

and others make additional choices. Their selections differ only in material media, of course. None-the-less, there has been an (almost) century-long controversy over which formulation is physically correct. The various formulations predict different force expressions in matter. Minkowski has

$$\bar{f} = \nabla\bullet\bar{T} - \frac{\partial(\bar{D}\times\bar{B})}{\partial t} = \bar{f}_L. \qquad \text{(A.I.8)}$$

Abraham has

$$\begin{aligned}\bar{f} &= \nabla\bullet\bar{T} - \frac{1}{c^2}\frac{\partial(\bar{E}\times\bar{H})}{\partial t}\\ &= \bar{f}_L + \frac{\varepsilon_r\mu_r - 1}{c^2}\frac{\partial(\bar{E}\times\bar{H})}{\partial t}\end{aligned} \qquad \text{(A.I.9)}$$

And, of course, Maxwell-Heaviside have

$$\bar{f} = \nabla\bullet\bar{T} = \bar{f}_L + \frac{\partial(\bar{D}\times\bar{B})}{\partial t}. \qquad \text{(A.I.10)}$$

Of these, only the Maxwell-Heaviside expression survives in vacuum to give a space-drive.

APPENDIX II. ZERO TIME-AVERAGE

Many years ago, an objection was raised, not to the reality of the Heaviside force, but to its accessibility. Since the force density is proportional to the time derivative of E×H, and the time average of the derivative is zero, won't the force average to zero? This was an issue raised by Slepian in his 1949 space-drive proposal. The "zero time-average theorem"[29,30] can be stated succinctly as follows:

The average of the derivative of any bounded quantity is zero:

$$\begin{aligned}\left\langle\frac{dg}{dt}\right\rangle &= \lim_{T\to\infty}\frac{1}{T}\int_0^T\left(\frac{dg}{dt}\right)dt\\ &= \lim_{T\to\infty}\frac{g(T)-g(0)}{T} = 0\end{aligned} \qquad \text{(A.II.1)}$$

Since g(t) varies only within finite limits, then as the time interval T increases without limit, the average value of dg/dt clearly goes to zero.

Panofsky and Phillips have asserted that, on a macroscopic level, the only classical quantities that have physical significance are those that have non-vanishing macroscopic space-time averages,[31] and this would appear to dispose of any phenomenology arising from the Heaviside term, $\left\langle \iiint_V \left(\frac{\partial \bar{g}}{\partial t}\right) dV \right\rangle$.

However, the veiled presuppositions of the theorem should be examined carefully. These are most clearly distinguished in the statement of the theorem as presented by H.A. Lorentz, himself. *"If the system is in a* <u>*stationary*</u> *state, the mean value of any quantity that is the derivative with respect to time of a quantity determined by the state of the system will vanish... The numerator is finite, but the denominator can be made to exceed any limit."*[32] Lorentz was, indeed, aware of the inherent assumptions nested within the theorem.

Nonstationary Systems

The question to be answered is, "What happens if the physical system is *non*stationary?" That is, what happens if the boundary conditions or volume limits of integration (and not just the integrands) are time varying? If the boundaries can somehow be manipulated to effectively *rectify* the integrand by means of a temporally discontinuous (*nonstationary*) physical action, such as might occur with time-varying boundary conditions, then the time-average of the *volume integrated* derivative will not necessarily vanish.

When one considers vector quantities, the theorem has rather interesting implications. For a vector function $\bar{F}$ that has been defined as the volume integral of the time-derivative of some vector density, $\bar{g}$, one has:

$$\langle\bar{F}\rangle = \left\langle \iiint_V \frac{\partial\bar{g}}{\partial t}\,dV \right\rangle \neq \iiint_V \left\langle\frac{\partial\bar{g}}{\partial t}\right\rangle dV. \qquad \text{(A.II.2)}$$

Consistent with Lorentz's remarks, the zero time-average theorem does *not* imply that $\langle\bar{F}\rangle = 0$ for nonstationary systems.

The Leibnitz Theorem

To illustrate this conclusion, consider the Leibnitz integral theorem from undergraduate calculus:

$$\frac{d}{dt}\left[\int_{a(t)}^{b(t)} g(x,t)dx\right] = \int_a^b \frac{\partial g}{\partial t} dx + \frac{\partial b}{\partial t} g(b,t) - \frac{\partial a}{\partial t} g(a,t) \qquad \text{(A.II.3)}$$

The theorem shows how to differentiate an integral whose integrand, g(x,t), as well as whose limits of integration, a(t) and b(t), are functions of the variable of differentiation.

Example

As an example of interest, suppose we have the following linear momentum density (notice that the corresponding cavity fields are reactive) and the simple *nonstationary* distributed system described by the parameters a(t) and b(t):

$$\begin{aligned} g(x,t) &= g_0 \cos(\omega t)\sin(\omega t) \\ a(t) &= 0 \\ b(t) &= b_0\left[1+\cos(2\omega t)\right] \end{aligned} \qquad \text{(A.II.4)}$$

where we have fixed one spatial boundary, a, and let the other boundary, b, oscillate sinusoidally about b_0. For the given parameters, the time average Heaviside force is found from Equation (13) and Leibnitz's Theorem as

$$\begin{aligned} \langle \bar{F} \rangle &= \left\langle \iiint_V \frac{\partial \bar{g}}{\partial t} dV \right\rangle \\ &= \left\langle \frac{d}{dt}\left[\int_{a(t)}^{b(t)} g(x,t)dx\right] - \frac{\partial b}{\partial t} g(b,t) \right\rangle \\ &= \frac{1}{2}\omega g_0 b_0 \end{aligned} \qquad \text{(II.5)}$$

which is nonzero. The issue is that for nonstationary systems the order of volume and time integrations becomes important. As with nonergodic systems, *the expected value of the integral is not identical to the integral of the expected value.* (Obviously!) Therefore, the zero time-average theorem does *not* imply that the time-average value of the Heaviside force must be zero.

APPENDIX III. WVU EXPERIMENTS

In an attempt to independently verify the conclusions of Graham and Lahoz, a subcontract was let to the Physics Department at West Virginia University where Dr. Alan Barnes is repeating the oscillating cylinder experiments. Professor Barnes has written this Appendix III as a description of his work.

Replication Of Graham-Lahoz

The momentum density in an electromagnetic field is described by Poynting's vector, $\mathbf{E}\times\mathbf{B}/c^2$. Although easily demonstrated in the case of free radiation or large power flows, the observation of momentum density in static electric and magnetic fields is technically difficult. Indeed only the 1980 experiment of Graham and Lahoz[33] has demonstrated a quantitative agreement between theory and experiment and their errors are about 20% of the size of the effect. To further study this fundamental aspect of momentum, we have begun a new series of measurements at West Virginia University.

These new measurements, like the Graham and Lahoz experiment, use a torsion pendulum to measure the change in angular momentum when a coaxial cylindrical capacitor is charged in a magnetic field to produce an $\mathbf{E}\times\mathbf{B}$ field between the capacitor plates. In their experiment Graham and Lahoz mounted the capacitor assembly on a torsion rod in the field of a superconducting magnet and charged the capacitor through leads running almost parallel to the magnetic fields. This gave rise to two unwanted effects: an unbalanced electromotive force on the capacitor leads during charging and a dependence of the oscillator Q-value on the alignment of the torsion pendulum with the magnetic field. The present experiment avoids these complications by putting all of the parts onboard the pendulum bob. The magnetic field is provided by permanent magnets and the battery powered unit is controlled optically from outside. Only forces arising from interactions with external fields need to be taken into account.

To give an idea of the challenge facing the experiment, the angular momentum content of the fully charged capacitor in the magnet is about 5×10^{-13} Kg m^2/sec. That is enough to set the torsion bob spinning at a rate of about 1.25×10^{-9} radians/sec or one revolution per 160 years.

Although this sounds difficult, the experiment is not impossible. The optical system used to measure this angle is sensitive to far better than 10^{-7} radians and driving the pendulum and observing the response synchronously at resonance greatly enhances the signal to noise ratio. Our goal is to have a one percent statistical error arising from the thermal noise in the system. Early measurements of the vibrational environment of the lab where this is being undertaken indicate we should be able to achieve this thermally limited goal without going to a special low vibration lab.

The conceptual and mechanical design of the apparatus is complete and first pendulum bob is presently under construction. A second design powered by a coaxial feed down the pendulum fiber is being pursued in parallel.

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RESEARCH ON ACHIEVING THRUST BY EM INERTIA MANIPULATION

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ABSTRACT

One of the challenges of interstellar travel being to discover a self-contained means of propulsion that requires no propellant, it has already been shown that a solution to the problem does exist, provided the system is endowed with tensor mass properties. The aim of this paper is to discuss a "propellantless" propulsion concept based on electromagnetic fields to modify the inertial properties of the system. Mass tensor properties were found to be replicated in Electromagnetism in connection with the still standing Abraham-Minkowski controversy. An experiment to settle the question has been implemented which consists of mounting the device as a seismic mass atop a mechanical suspension. Results gathered during the 1993 – 1997 period consistently point to a mechanical vibration induced by matter-EM field momentum exchange, as predicted by Minkowski's formulation, after all other sources of vibration were taken into account, or removed when possible. Tests conducted since 1999 on a redesigned experiment aiming at getting rid of most of the identified spurious effects, yield comparatively sharper and clearer evidence of sustained thrusting. However, it must yet be seen as an "anomalous" effect, since the system momentum is not conserved; thus further work remains to be done to confirm these results.

INTRODUCTION

Human interstellar exploration may not be possible without the discovery of a self-contained means of propulsion that requires no propellant.[1] This formally translates into the problem of achieving "jet-less" propulsion of spaceships that can then be seen as closed systems, i.e., without external assistance or mass/energy exchanges with the surrounding medium. It follows from this picture that the 4-Momentum of the system should be conserved. As already shown, a formal solution to the problem does exist, provided the system is endowed with tensor mass properties. This is embodied in the Covariant Propulsion Principle (CPP) which derives from a mass tensor description of the closed system consisting of the rocket driven spaceship and its propellant mass, provided the "solidification" point is other than the system center of mass, within a relativistic covariant formulation.[2]

The mass tensor formulation shows that the propulsion effect is to be related to the deviatoric part of the tensor, which exhibits the particularity of producing a non-vanishing linear momentum in the spaceship comoving Lorentzian frame. This can be seen as the physical signature of a non-diagonal 4-mass tensor. The situation is reminiscent of the concept of static EM field momentum which can develop in the rest frame of a physical arrangement of electric and magnetic sources including polarizable media, as depicted in Fig. 1.

Different theoretical results are possible depending whether Planck's principle of inertia of energy is satisfied or not in the relationship between the Poynting vector (energy flow density) and the electromagnetic momentum density.[3] These different results are basically Abraham's and Minkowski's forms of the EM momentum density, as the three dimensional expression of the so called "Abraham-Minkowski controversy" about the correct Energy-Momentum tensor of EM fields in polarizable media. The controversy, lasting since 1909, strikingly remains as a yet unsolved issue of Physics.[4,5] Supporters on the theoretical aspect split about equally between the two forms, according to literature reviews, while existing experimental evidence does not allow to draw definite conclusions.

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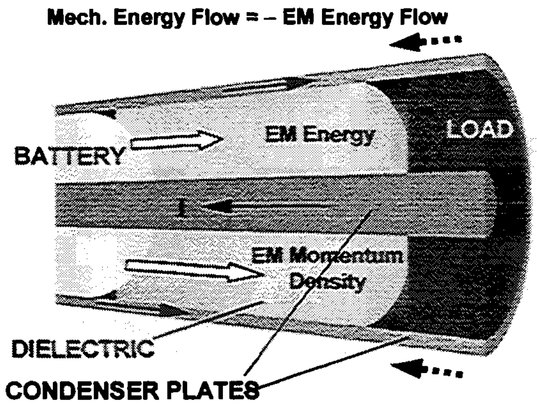

$$\text{EM Momentum Density} \begin{cases} = \text{EM Energy Flow} / c_0^2 \\ \\ = \text{EM Energy Flow} / c^2 \end{cases}$$

Fig. 1 Different determinations of the EM momentum density in the "matter" rest frame with polarizable media.

In the present work, by using Minkowski's formalism,[6-8] a non-vanishing momentum of electromagnetic origin is shown to arise for the particular device depicted in Fig. 1. The whole system would then enjoy tensor mass properties of electromagnetic origin, when viewed as a single particle at rest in the "matter" subsystem frame. It follows that the EM field, given suitable charge and current distributions, can modify the inertial properties of the generating device, giving rise to the possibility of obtaining mechanical impulses on the device, not undergoing any exchange of mass-energy with the surrounding medium, as stated by the CPP. A propulsion concept based upon this kind of inertia manipulation mechanism is subsequently drawn; the experimental setup built to test that concept is discussed, as well as the obtained results and the applied signal processing techniques.

THRUST BY TENSOR MASS "WARPING"

The Relativistic Rocket Approach

A fully covariant reformulation of the relativistic rocket motion has been achieved and the two-particle and one-particle models of the related physical system were analyzed in Ref. 2, together with the effect of a generalized "solidification point" location, w.r.t. the center of mass (c.m.) location. When the whole system (Rocket + Ejecta) is analyzed as a single particle located at the "Rocket" system c.m. (or any "structural" point), a mass tensor is readily found as related to the whole system which reads in geometric notation

$$\mathbf{M} = \left(m_0 + m_E^*\right)\mathbf{I} + \left(\mathbf{p}_E \wedge \mathbf{v}\right) / c_0^2 . \qquad (1)$$

where m_0 and m_E* represent the masses of the rocket and of the ejecta in the rocket rest frame, $\mathbf{I}$ is the identity 4-tensor, $\mathbf{p}_E$ the 4-momentum of the ejecta and $\mathbf{v}$ the 4-velocity of the "solidification point". For a closed system ($\mathbf{f} = \mathbf{0}$),

$$d\left(\mathbf{M}\cdot\mathbf{v}\right) = \mathbf{0} \quad \Rightarrow \quad \mathbf{M}\cdot d\mathbf{v} = -\,d\mathbf{M}\cdot\mathbf{v}, \qquad (2)$$

thus, the 4-acceleration of the chosen "solidification point" is to be related to the rate of variation of the mass tensor deviator, this being written as

$$m_0\, d\mathbf{v} = -\left(d\mathbf{p}_E \wedge \mathbf{v}\right)\cdot\mathbf{v} / c_0^2 . \qquad (3)$$

Eq. (3) shows that to have zero "Rocket" 4-acceleration for any 4-velocity, ($d\mathbf{p}_E \wedge \mathbf{v}$) must vanish, i.e., the deviatoric part of the mass tensor variation must vanish. It is also shown that this comes out as a necessary condition for vanishing acceleration.

The Covariant Propulsion Principle

Now, to achieve 4-acceleration, anisotropy of the mass tensor must follow at some instant and, as a result, a non-vanishing 3-momentum shows up in the spacecraft comoving Lorentz frame. An elementary algebraic analysis shows that a mass 4-ellipsoid arises as a "geometrical" representation of the mass tensor; a given variation of this tensor, related to a propulsion effect, can be viewed as a mass 4-ellipsoid warping, giving rise to the Covariant Propulsion Principle: *A spaceship undergoes a propulsion effect when the whole system mass 4-ellipsoid warps.*[2]

The C.P.P. furnishes an alternative wording for the Action and Reaction Principle (A.R.P.) which is known to fail in relativistic mechanics even in its weak form; it does not substitute the four-momentum conservation law, but extends its meaning to complex systems when they are represented as pointlike particles which are not collocal with the whole system center of mass. They are both derived concepts which allow, in their domains of validity, for an intuitive representation of the involved propulsion mechanisms. In the same way the A.R.P. allowed for the "mass-spring" analogy as an intuitive model, the C.P.P. allows for the essentially geometrical analogy with the *jétée* motion of the ballet dancer, during which she gets angular acceleration by retracting her extremities onto the gyration axis, i.e., by ***warping its inertia tensor*** in 3-D space. As for the propulsion case, a linear acceleration/deceleration is achieved by ***warping the mass tensor***, which must be defined in

Minkowski's 4-D space. A pictorial representation of the propulsive effect is shown in Figs. 2 and 3, where a mass ellipsoid is assigned to a "Flatland" rocket system.

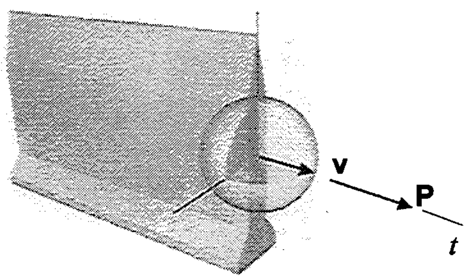

Fig. 2 "Flatland" rocket at rest in its 3-D spacetime and the corresponding mass ellipsoid.

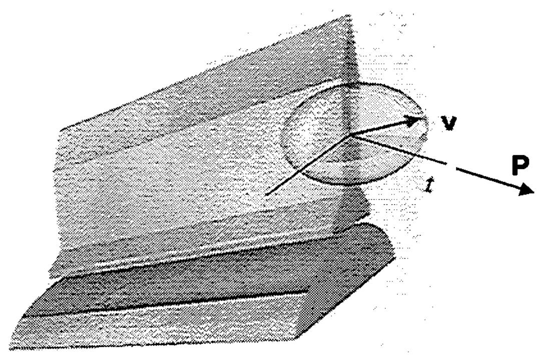

Fig. 3 "Flatland" rocket after acceleration in its 3-D spacetime and the corresponding mass ellipsoid.

Studies about inertia as something that could be manipulated for propulsion purposes are not new, a tentative explanation has already been undertaken on the basis of the relativistic mechanics of extended bodies under electrostatic pressures.[9] However, the C.P.P. allows for a general formulation of the problem, provided a "propulsion field" of 4-momentum $\mathbf{p}_F$ can be ascribed to the whole system, analog to the rocket ejecta subsystem. The system can then be viewed as a single particle located at the "matter" system c.m. (or any "structural" point) so that a mass tensor is readily found as related to the whole system. The 4-acceleration of the chosen "solidification point" now becomes

$$m_0 \, d\mathbf{v} = -\left(d\mathbf{p}_F \wedge \mathbf{v}\right) \cdot \mathbf{v} / c_0^2 . \qquad (4)$$

Thus, the 4-thrust on the single particle, in any arbitrary frame, is given by

$$\mathbf{F} = -\frac{d\mathbf{p}_F}{d\tau} . \qquad (5)$$

Equation (5) expresses, as expected, the law of conservation of the total system energy-momentum, consistently with Equation (2). The change of the mechanical (matter) momentum exactly balances the change of the propulsion field momentum; momentum is then being exchanged within the whole closed system. The device works as a propulsion field momentum "accumulator" whereas the mechanical momentum that can be drawn from it is, by present Physics paradigms, limited to the propulsion field momentum amount.

ELECTROMAGNETIC MASS TENSOR

Since mass tensor anisotropy means non-vanishing 3-momentum in some convenient frame, question arises about the general existence conditions of momentum of electromagnetic origin in the "matter" comoving frame. A fully covariant formulation of the problem requires to consider the Energy-Momentum tensors for a closed physical system consisting of "matter" and EM fields. By applying the Law of 4-Momentum Conservation to the particles and fields contained in any four-dimensional region of space-time bounded by a closed, three-dimensional surface, the system 4-momentum is found, for closed systems, to be conserved in time. Now, if the observer's frame coincides with the frame where the "matter" is at rest when no EM field is present, the condition for anisotropic mass tensor when the EM field is ON, means that in no case the system 4-momentum aligns with the observer's 4-velocity.[10] These are global consequences of mass tensor anisotropy.

When consideration is given to the locality of the energy-momentum conservation law, the following relationship can be found for the volume integral of the momentum densities[11]

$$\int_V \left(g^{(m)} + g^{(f)}\right) dV = - \int_V x \, div\left(g^{(m)} + g^{(f)}\right) dV . \qquad (6)$$

By introducing the relationship between energy flow and momentum density, and assuming that Plank's principle of inertia of energy does not necessarily hold for the EM energy flux, such as a field of group velocity c of electromagnetic waves propagation exists, Eq. (6) becomes

$$\int_V \left(\boldsymbol{g}^{(m)} + \boldsymbol{g}^{(f)}\right) dV = \int_V \frac{x}{c_0^2}\left[\frac{\partial w}{\partial t} - grad\left(\frac{c_0}{c}\right)^2 \cdot \boldsymbol{s}^{(f)} + \left(\frac{c_0^2}{c^2} - 1\right) div\, \boldsymbol{s}^{(f)}\right] dV, \tag{7}$$

with w standing for the mass-energy density.

Transient Regimes

It can be seen that to obtain non-zero total momentum for specific matter-field configurations, a non-vanishing energy density variation rate is a sufficient condition. It is a sufficient condition for any matter-field configuration, provided Planck's principle of inertia holds within polarizable matter too.

Mass tensor anisotropy, as related to a special frame, can thus arise when net mass-energy fluxes take place within closed systems where Planck's principle of inertia holds everywhere, or, in other words, when the system is under anisotropic non-equilibrium conditions.

Stationary Regimes

Eq. (7) becomes, for stationary regimes and any matter-field configuration

$$\int_V \boldsymbol{g}^{(f)} dV = . - \int_V x\left[grad\left(\frac{1}{c^2}\right) \cdot \boldsymbol{s}^{(f)} + \left(\frac{1}{c^2}\right) div\, \boldsymbol{s}^{(f)}\right] dV \tag{8}$$

The quantity between brackets being $div\, \boldsymbol{g}^{(f)}$, a non-zero LHS is possible provided $\boldsymbol{g}^{(f)}$ is not divergence-free everywhere. This can be achieved for arbitrary matter-field configurations if gradients of EM wave propagation group velocity occur in the integration region, i.e., as assumed for the derivation of Eq. (7), Planck's principle of inertia does not hold within polarizable media, in which case the energy-momentum tensor becomes unsymmetrical. This is the case for the setup shown in Fig. 4, where $div\, s^{(f)} = 0$ everywhere and a non-vanishing total EM momentum can only arise from the RHS first term of Eq. (8). The contributions for the volume integral come from the free surfaces of the dielectric, through which jumps of the velocity of light take place in the direction of the EM energy flux.

For this particular setup, transient regimes do not allow to produce an EM momentum contribution since energy density variation rates distribute symmetrically throughout the setup regions.

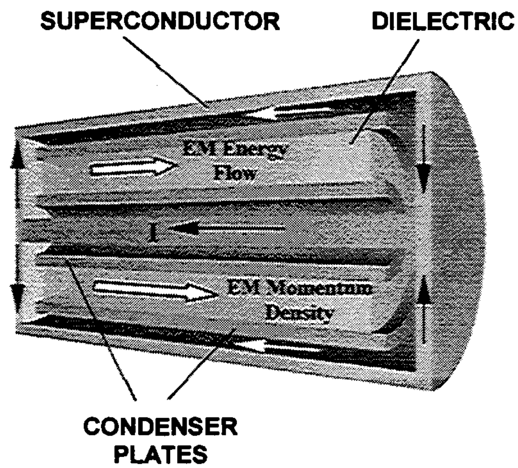

Fig. 4 Stationary regime in the 'matter 'rest frame with polarizable media.

THE ABRAHAM-MINKOWSKI CONNECTION

A non-vanishing EM momentum in the stationary case implies that the whole system Energy-Momentum tensor is unsymmetrical; this is a rather uncomfortable property for a system assumed to be a closed one. Either the assumption that Planck's principle of inertia of energy does not hold everywhere is false, or the system is open and one must consider an extended closed system to which the present one belongs. The first possibility, as far as stationary regimes are considered, completely precludes a closed system to bear a tensor mass; the second possibility leads to the question about what that extended closed system is like. A hint comes from the fact that the "excess" EM momentum behaves as an "external" stress in 4-space. As a conjecture, if ZPF (Zero Point Field) were a physical reality for describing inertia,[12] that "excess" EM momentum could be explained as a form of "directed", anisotropic vacuum fluctuations of EM energy. The sought extended system would then happen to be space-time itself.

The existence conditions are consistent with the use of Minkowski's Energy-Momentum tensor for the EM field.[3] By definition, the Relativistic Mechanics Laws of Conservation are satisfied; the same being true, nevertheless, for Abraham's Energy-Momentum tensor, together with other forms of the electromagnetic Energy-Momentum tensor. This is precisely the still-standing[4,5] Abraham-Minkowski controversy about the form of that Energy-Momentum tensor, specially for low frequency or quasi-stationary fields.[3,13-15] It reduces, basically, to the discrepancy around the mathematical expression of the EM momentum density:

$$\textit{Abraham's claim:} \qquad g^A = \frac{(E \times H)}{c_0^2}, \qquad (9)$$

$$\textit{Minkowski's claim:} \qquad g^M = (D \times B). \qquad (10)$$

The issue is thus highly relevant to "propellantless" propulsion, since the resultant total EM 4-momentum acts exactly as the generic propulsion field $\mathbf{p}_F$ in Eq. (5), so EM inertia manipulation becomes a theoretical possibility. Experiments to definitely settle the question were still missing besides some partialized attempts,[16-19] leading to non conclusive enough results. A positive answer for Minkowski's EM tensor would allow to obtain "jet-less" propulsive effects by EM fields manipulation; furthermore, it could mean an indirect demonstration of the physical reality of ZPF.

A propulsion concept based upon this kind of inertia manipulation mechanism can subsequently be drawn. It basically consists on suitably grouping the sources of electric and magnetic fields within a rigidly connecting device, as depicted in Fig. 4. By doing so, a stationary Minkowski's EM field momentum can develop thanks to the dielectric filled region; by controlling the intensities of these fields, the inertia properties of the system as a whole, when represented by its "matter" part – the device –, are allowed to change so that a conversion of the EM field momentum into mechanical momentum of the device is expected to happen, and reciprocally; again if Minkowski is right. Nevertheless, it must be realized that this device works as an EM momentum "accumulator". The mechanical momentum that can be drawn from, is, in accordance with present Physics paradigms, limited to the "accumulated" EM momentum amount.

ALTERNATE THRUST EXPERIMENTS

Experimental Setup Rationale

An electromagnetic momentum generator (EMMG), based on the schematics of Fig. 5, was engineered up to the "proof of concept" level and an experiment was designed aimed to verify that: a) Minkowski's EM Energy-Momentum tensor does properly describe the electromagnetic field-matter interactions in polarizable media. b) Global EM momentum in the matter rest frame of a closed system is being generated, or, equivalently for such a system, a non scalar 4-mass tensor behaviour is being obtained. c) The experimental thruster is applying mechanical forces on the test stand without expenditure of mass, besides that equivalent to the radiant energy dissipated from the system (e.g., Joule heating), which cannot account for the observed effects.

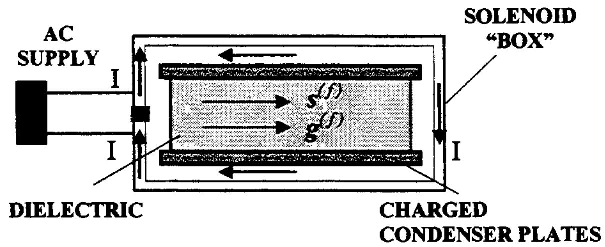

Fig. 5 EM Momentum Generator schematics.

An experimental setup was accordingly built up which consists of mounting the device as a seismic mass atop a mechanical suspension. A supply of 6 A - AC (square wave) to the coils and 4 kV - DC to the capacitors allows for a total EM momentum (Minkowski's formulation) of around 1.E-8 Ns (square wave), by using $BaTiO_3$ ceramic dielectrics. The alleged conversion of Minkowski's EM momentum into mechanical momentum of the EMMG in turn generates forces acting upon this device. By means of a square wave activation of the device at a frequency close to the fundamental frequency of the seismic suspension, the supporting blade of the test fixture can be made to resonate so an amplified upper end displacement response is obtained.

Displacements in the range 10^{-8} - 10^{-7} m were to be expected. Piezoceramic strain transducers were devised to detect this range of displacements, taking into account technological as well as financial constraints. PZTs output voltages proportional to the strain level in a broad dynamic range, achieving sensitivities (seismic and acoustic threshold in controlled environments) up to 10^{-11} m/m.[20] This is two orders of magnitude lower than the expected levels, as related to the sensing fixture shown in Fig. 6. However, the full signal includes ground and environment induced noise as observed in preliminary testing. This microseismic excitation can account for displacements comparable to those expected to be caused by the investigated effect, with a narrow band frequency response centered in the first natural frequency of the sensing fixture.

Another source of unwanted noise is the residual interaction between the coils and the Earth magnetic field, which can account for equally comparable total displacements, albeit with a deterministic distribution in the frequency domain. A third source of noise relates to the magnetic interaction between the moving and the fixed parts of the AC and DC circuits (self magnetic interaction), those belonging to the device atop the resonant blade and to the external power supply respectively. It was also found to contribute to the displacements on practically the same foot as the formerly two mentioned sources but at twice the coil activation frequency.

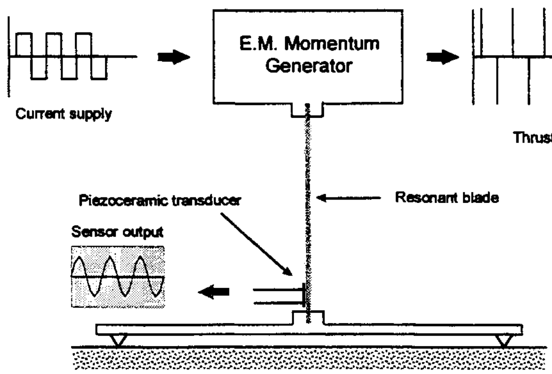

Fig. 6 Micromotion sensing concept.

Other sources of noise have been considered, too, like air motion, electrostatic couplings, sound, radiometric effects, spherics, etc, which can have a degrading effect on the measurements quality, although to a lesser extent than the forementioned sources. The overall estimated effect amounts to -60 dB < S/N < -40 dB at the transducer output and the need for further processing arises. To this aim, the analog transducer output signal is digitalized through a 12 Bit data acquisition board, making it available to PC based storage devices.

Test Implementation and Philosophy

Two series of tests were conducted during the period 1993 - 1997. Only one measurement channel was available along the first series of tests with no vibration isolation provisions. The second test series included, besides the main transducer measurement channel, a dummy seismic fixture with its transducer and measurement channel, a voltage supply measurement channel, and a vibration-free table. In both series data was acquired in 5000 samples sequences at a rate of 500 samples/sec. Power Spectral Density (PSD) using Welch's averaged periodogram method was estimated over a 2048 length frequency interval. The test philosophy was based upon comparison of results in the frequency domain, due to different excitation schemes. These were: A) Ground induced noise. B) Coils ON, capacitors OFF + (A). C) Coils ON, capacitors ON + (A). D) Coils OFF, capacitors ON + (A).

Following modeling and simulation activities, geomagnetic and self-magnetic interaction noises were expected to appear in (B) and (C) as compared to (A), while the influence of the capacitors should appear in (C) as compared to (B) if thrust by inertia manipulation is acting upon the device; no difference was expected to arise beween (D) and (A), since static electric fields alone cannot account for the vibratory behavior of the sensing fixture.

First Test Series

Results corresponding to the first test series are shown in Figs. 7-10 where, as expected, differences can be observed between the (A) and (B) spectra, mainly caused by geomagnetic noise. Differences can also be observed between the (A) and (C) spectra, but there are intriguing differences between the (B) and (C) spectra, while again, as expected, no difference appears between the (A) and (D) spectra.

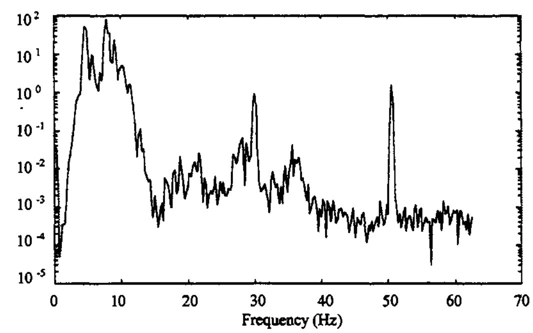

Fig. 7 First test series PSD [V^2/Hz] – Case (A)

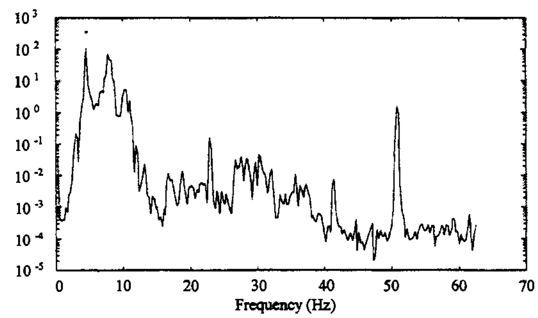

Fig. 8 First test series PSD [V^2/Hz] – Case (B)

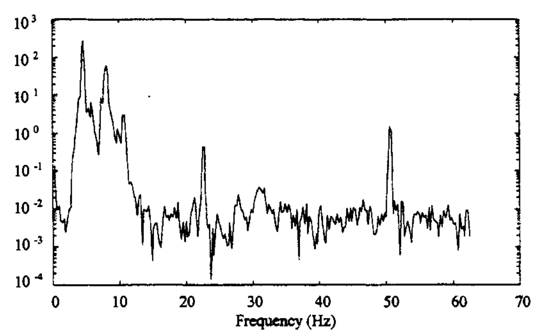

Fig. 9 First test series PSD [V^2/Hz] – Case (C)

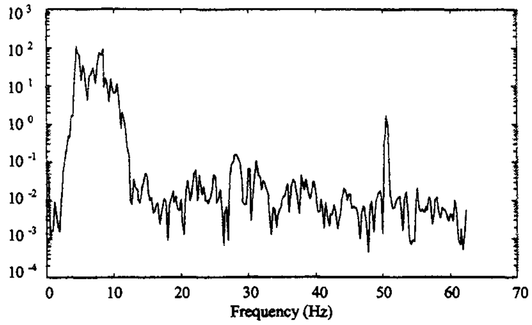

Fig. 10 First test series PSD [V^2/Hz] – Case (D)

Second Test Series
Since a significant amount of ground induced noise was observed during the first test series, a second test series was performed with the improved setup as mentioned before. It was also decided to proceed to intensive signal processing so as to achieve a higher confidence in the EMIM (Electro-Magnetic Inertia Manipulation) effect detection. Data gathered during this second series of tests, was firstly processed to achieve a system identification on the basis of the ground motion excitation only. An ARMA (Auto Regressive Moving Average) model structure was then identified; later, inverse filtering was performed for every output sequence in order to obtain the equivalent ground motion; then, filtering by the vibration isolation fixture led to the reconstruction of the sensing device base motion; finally, optimal filtering (Wiener filter) was performed on the resultant ouput, using the EMMG induced excitation as the "desired" signal.

Raw data exhibit, when transformed to the frequency domain, nearly the same pattern as those of the first test series. However, they show, after processing, a more accurate spectral structure as related to the sought excitation spectrum which consists of equal amplitude odd harmonics of the square wave fundamental frequency, as shown in Fig. 11. Spectrum (A) contains low level residuals induced by the Wiener filter - a sort of numerical artifact - as well as Spectrum(D); Spectrum (B) does not match the "message" spectrum, it better fits that of the geomagnetic noise square wave excitation; Spectrum (C) shows a structure which strongly suggests an alternate impulsive excitation, as it turns out to be when a square wave EM field-matter momenta exchange is present. The figures are representative of around 16 sequences by case. Better detectability can be obtained by means of statistical analysis over the whole ensembles and adaptive noise cancellation procedures, either on the raw output data or on the inverse filtered output data.[21-23]

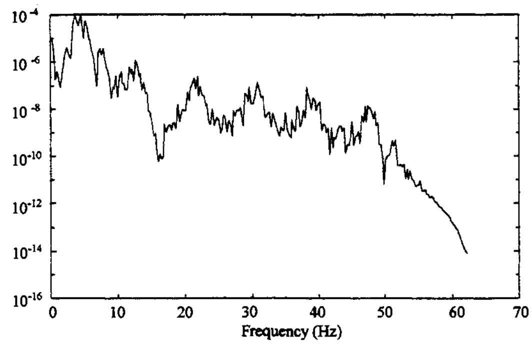

Fig. 11 Second test series PSD [V^2/Hz] – Case (A)

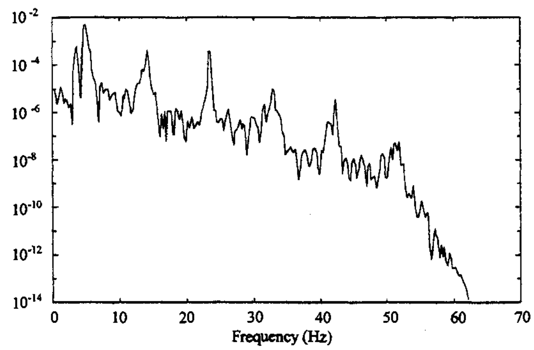

Fig. 12 Second test series PSD [V^2/Hz] – Case (B)

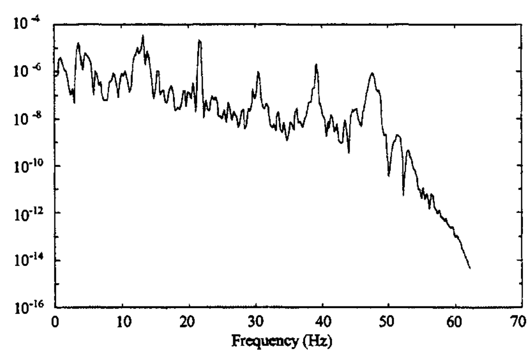

Fig. 13 Second test series PSD [V^2/Hz] – Case (C)

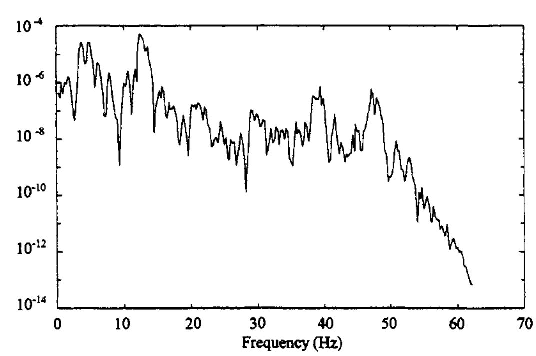

Fig. 14 Second test series PSD [V^2/Hz] – Case (D)

SUSTAINED THRUST EXPERIMENTS

Third Test Series

Notwithstanding the improvements implemented on the second test series, uncertainties still remained which could account for the observed "positive" results, regarding especially to:

a) Geomagnetic influence.
b) Numerical artifacts as in Figs. 11, 14.
c) Colored ground noise centered around the excitation frequency.
d) Air motion (ionic wind).
e) Power supply induced EMI.

In order to get rid of these interfering effects, the experiment was modified during 1999, according to an alternative formulation of the Abraham-Minkowski controversy, this time in terms of force densities. If dispersion is negligible and the medium is allowed to be spatially inhomogeneous and anisotropic, $D_i = \varepsilon_{ik}E_k$, $B_i = \mu_{ik}H_k$. The force densities are given by[3, 8]

$$\boldsymbol{f}^M = \rho \boldsymbol{E} + \boldsymbol{j} \times \boldsymbol{B} - \tfrac{1}{2} E_i E_k \nabla \varepsilon_{ik} - \tfrac{1}{2} H_i H_k \nabla \mu_{ik}, \quad (11)$$

$$\begin{aligned} \boldsymbol{f}^A = \boldsymbol{f}^M &- \nabla \cdot (\boldsymbol{DE} - \boldsymbol{ED}) - \nabla \cdot (\boldsymbol{BH} - \boldsymbol{HB}) \\ &+ \frac{\partial}{\partial t}\left(\boldsymbol{D} \times \boldsymbol{B} - \frac{1}{c_0^2} \boldsymbol{E} \times \boldsymbol{H} \right) . \end{aligned} \quad (12)$$

With the isotropic medium approximation Eqs. (11) and (12), reduce to

$$\boldsymbol{f}^M = \rho \boldsymbol{E} + \boldsymbol{j} \times \boldsymbol{B} - \tfrac{1}{2} E^2 \nabla \varepsilon - \tfrac{1}{2} H^2 \nabla \mu , \quad (13)$$

$$\boldsymbol{f}^A = \boldsymbol{f}^M + \frac{\varepsilon_r \mu_r - 1}{c_0^2} \frac{\partial}{\partial t} (\boldsymbol{E} \times \boldsymbol{H}) . \quad (14)$$

These force densities clearly differ inside matter for generic fields; they are however identical for static fields, irrespective of the medium. If harmonic fields are considered, the force densities instantaneous values differ but their averaged values become identical and therefore useless for discriminating between the two formulations. This is the reason Walker&Walker's claim,[18] favoring Abraham's one, is essentially wrong and the experiment remains inconclusive.

The EM inertia manipulation (EMIM) experiment was modified in such a way that both $\boldsymbol{D}$ and $\boldsymbol{B}$ fields were subjected to harmonic evolution. The averaged effect of the total EM force was sought after, so Eq. (13) must be used for its theoretical estimation as applied to the schematics of Fig. 5. This estimation can proceed straighforwardly by neglecting capacitor edge effects, by considering the coils as a conducting "box" bearing a negligible voltage w.r.t. to the capacitor plates and by assuming that the polarization current within the dielectric contributes to the second term of Eq. (13).

As a result, electric self-interaction, represented by the first term of Eq. (13) and magnetic self-interaction represented by the second term of the same equation, simply cancel out. Since non-magnetic matter is involved, contribution to the total EM force acting upon the device comes from the third term. This contribution is non-zero through the boundaries of the dielectric filled volume. Since induced electric fields of magnitude E_i appear on these boundaries yielding an unbalancing effect on the electric field of magnitude E set by the capacitor, the integrated effect does not cancel out in the $\boldsymbol{E} \times \boldsymbol{H}$ direction and can be written as ($\varepsilon_r >> 1$)

$$F = 2 \varepsilon_r \varepsilon_0 E E_i A_L , \quad (15)$$

where A_L represents the lateral open surfaces of the dielectric. Application of the formula for parallel plates capacitor of width d, Lenz's Law and Ampere's Law for an infinite length solenoid of n turns, yields the following expression for the EM instantaneous thrust, as a function of the harmonic voltage $V \sin \omega t$ on the capacitor and the harmonic current $I \sin(\omega t + \phi)$

$$F = -\frac{\varepsilon_r \varpi n I V d}{c_0^2} \left(\frac{1}{2} \sin 2\varpi t \cos\varphi - \sin^2 \varpi t \sin\varphi \right) . \quad (16)$$

The averaged value then results

$$\langle F \rangle = \frac{\varepsilon_r \varpi n I V d}{2 c_0^2} \sin\varphi , \quad (17)$$

with maxima at $\varphi = \pm \pi/2$. The results obtained with Walker&Walker's experiment are consistent with this formulation and can, as the authors readily did, be interpreted in terms of the polarization current contribution to the Lorentz force.

However, Eq. (17) must be seen as a conflicting result if total momentum must be conserved, as stated previously. In fact, the standard treatment of the problem requires the polarization current to be excluded from the magnetic contribution to the Lorentz force, the self-magnetic interaction does not longer cancel out and Eq. (16) must be corrected as follows

$$F = 2\varepsilon_r \varepsilon_0 E E_i A_L - \dot{P} B V_C \ , \qquad (18)$$

where V_C stands for the capacitor volume filled with the dielectric. By adopting the same assumptions as for the derivation of Eq. (16), the second term of Eq. (18) becomes

$$F_{(2)} = -\frac{\varepsilon_r \varpi n I V d}{c_0^2}\left(\frac{1}{2}\sin 2\varpi t \cos\varphi + \cos^2 \varpi t \sin\varphi\right) \qquad (19)$$

so the total "standard" force is

$$F^S = -\frac{\varepsilon_r \varpi n I V d}{c_0^2}\left(\sin 2\varpi t \cos\varphi + \cos 2\varpi t \sin\varphi\right), \qquad (20)$$

and the averaged value goes to zero.

Therefore, the modified EMIM experiment should allow to discriminate between the "standard" and the presently proposed formulation of the averaged EM force. To take advantage of the sensing device characteristics, the voltage supply is reversed at a frequency different from the supply frequency, so the seismic setup is put into vibratory motion if the "proposed" formulation is correct. By detecting this force, the interfering effect (a) becomes averaged out; direct detection also permits to overcome the interfering effect (b) since no Wiener filtering is necessary; if the voltage reversing frequency is different from the setup natural frequencies, the interfering effect (c) becomes less significant and air motion (d) being related to the power supply frequency averages out too. Uncertainties are expected to remain regarding interfering effect (e).

Experiments were performed according to the test philosophy of the preceding test series. A reversing frequency of 30 Hz was chosen. Propulsive effects show up only when the Caps ON – Coils ON condition holds. Furthermore, maxima are obtained for a voltage-current phase shift of nearly 90 degrees, as predicted by the proposed formulation. A comparison of case (C) results with the corresponding simulation results (dotted line) is shown in Fig. 15, where a close agreement is found for the response to the alleged EMIM averaged force at 30 Hz reversing frequency. A comparison between cases (A) and (C) is shown in Fig. 16. Phase shift dependence is shown in Fig. 17, where experimental PSD peak values at 27 Hz are plotted against the voltage-current shift angle.

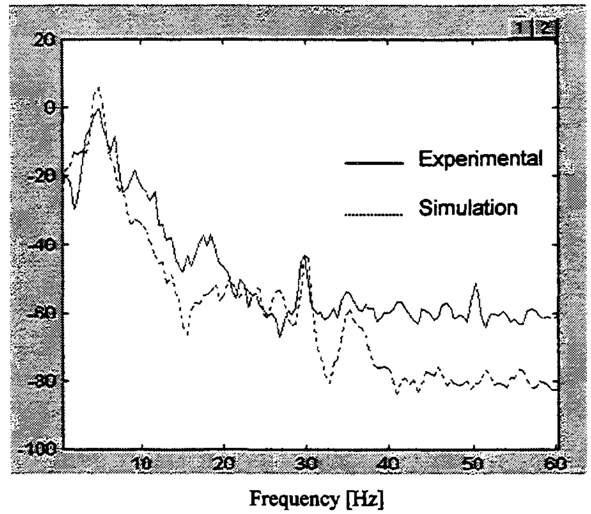

Fig. 15 Third test series PSD [dB] – Case (C) experimental and simulation results.

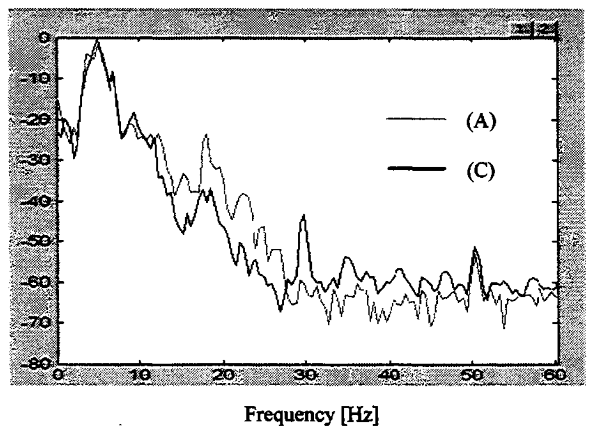

Fig. 16 Third test series PSD [dB] – Cases (A)&(C).

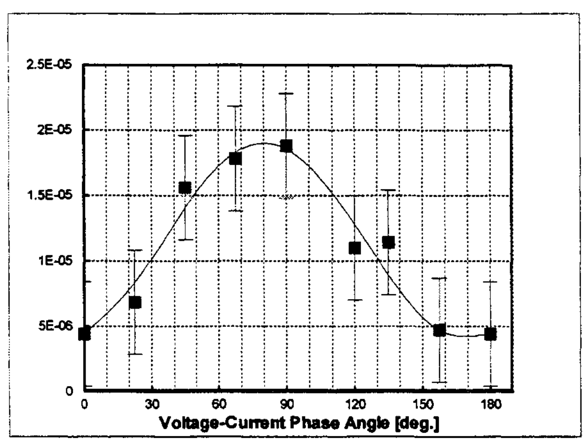

Fig. 17 Third test series average PSD peak values [V^2/Hz] @ 27 Hz, with 90% confidence intervals.

Spreading of the PSD peak values for a given angle was initially thought being due to contributions of magnetic interactions between the capacitor and the coil circuits during non-synchronized voltage reversings and/or between the capacitor circuit and the geomagnetic field. However, order of magnitude estimations show those interactions to be unable to account for the observed deviations. Their source remains unknown, so far, except for fluctuations of ground noise components at the reversing frequency. Nevertheless, a slightly shifted squared sine trend can clearly be seen to emerge from the plotted data.

LAYMAN'S SUMMARY

Either to go to the stars or, more pragmatically, to substantially cut down space transportation costs, new propulsion mechanisms must be found which get rid of propellants and/or conventional external assistance, i.e., the mythical "space drive" must still be invented.

Recent theoretical works show that jetless–sailless–beamless–tetherless propulsion can be achieved by manipulating the spaceship inertia in a way analogous to a dancer who increases her angular velocity by manipulating her body moment of inertia. To do that, an "extended" spaceship including the fields it eventually generates must be considered; a thrust then appears on the "material" spaceship by means of momentum exchange with its "field" complement.

This research has been conducted with the goal of checking whether the electromagnetic field is suitable for the above-mentioned purpose, since it can be shown that a theoretical formalism (Minkowski´s) gives credit to that possibility. Experiments were designed and performed which, in an exploratory phase, gave indirect evidence of Minkowski´s approach being valid. In a second and ongoing phase, following slight changes of the experiment implementation, direct and clearer evidence of sustained thrust (as it should be for operational propulsion) is being found.

However, the sustained thrust must, in principle, be seen as an "anomalous" effect since the Law of Momentum Conservation seems to be violated. This casts doubts about the validity and/or interpretation of the results and further experimental work, including in-orbit testing, is required to arrive to safer conclusions. If the effect still remains, propellantless propulsion would have been achieved but additional theoretical work will be needed for the full understanding of the underlying physical principles.

CONCLUSIONS

Theoretical as well as experimental research about a propellantless propulsion concept has been presented. On the theoretical side, thrusting without reaction mass or beamed power, seems to be possible by EM inertia manipulation, provided existence conditions hold, as those consistent with Minkowski's Energy-Momentum tensor for the EM field. However, the validity of this formalism is presently arguable under the still-standing Abraham-Minkowski controversy, the main argument being the unsymmetrical nature of that tensor. Experimental elucidation of the controversy was sought after and instrumented around a so called EMIM force-producing device.

Tests performed during the period 1993 - 1997 produced results which after intensive data processing, consistently pointed to a mechanical vibration induced by mass/inertia tensor warping of the device, or matter-electromagnetic field momentum exchange, as predicted by Minkowski's formalism. However, no direct detection of the sought effect has been obtained up to now; the experimental setup overall detectability needs further improvements, jeopardized by several potentially interfering effects.

A third series of tests conducted during 1999 and 2000 on a redesigned experiment to get rid of most of the identified spurious effects, yield comparatively sharper and clearer evidence of EMIM induced effects, albeit in contradiction with null results predicted by the "standard" formulation of global EM forces. Moreover, the results seem to indicate that the system momentum is not conserved, casting severe doubts about their validity; however, a conclusive demonstration that this is absolutely forbidden by the laws of Physics has not yet been provided and future breakthroughs in understanding the nature of inertia and motion may lead to more optimistics prospects. On the other hand, the alternative formulation presented in this paper correctly predicts peer-reviewed experimental results.

Further work still remain to be done to confirm these results, especially from the viewpoint of power supply induced EMI on the measurement channels, sharing the same spectral signature with the pursued effect, which could be overcome by means of Interferometer/Doppler vibrometry techniques. Another noise source was identified as being related to self-magnetic interactions in wiring and windings of power-supply components. Although efforts have already been made to filter out its influence from the experimental data, safer results will be obtained by a substantial increase of power. This will allow to use a reversing voltage frequency close to the fundamental frequency of the sensing device, in order for the alleged observable effect to show up well over the ground induced noise. In-orbit testing will indeed provide final answers, by simultaneously getting rid of all mentioned interferences.

ACKNOWLEDGMENTS

The author wishes to thank the U.S. Air Force Research Laboratory for supporting the presentation of this work under its Windows-on-Science Program, and to NASA BPP Project for procuring that help. Support from the Argentine National Agency for the Advancement of Science and Technology under Grant PICT-99-10-07107, and "Instituto Universitario Aeronautico" of Cordoba, Argentina, are also gratefully acknowledged.

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Experimental Results of Schlicher's Thrusting Antenna

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EXPERIMENTAL RESULTS OF SCHLICHER'S THRUSTING ANTENNA*

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Abstract

Experiments were conducted to test the claims by Rex L. Schlicher et.al. (Patent 5,142,861) that a certain antenna geometry produces thrust greatly exceeding radiation reaction, when driven by repetitive, fast rise and relatively slower decay current pulses. In order to test this hypothesis, the antenna was suspended by strings as a 3 m pendulum. Current pulses were fed to the antenna along the suspension path by a very flexible coaxial line constructed from loudspeaker cable and copper braid sheath. When driving the antenna via this cabling, our pulser was capable of sustaining 1200 A pulses at a rate of 30 per second up to a minute. In this way, bursts of pulses could be delivered in synch with the pendulum period in order to build up any motion. However, when using a laser beam passing through a lens attached to the antenna to amplify linear displacement by a factor of at least 25, no correlated motion of the beam spot could be detected on a distant wall. We conclude, in agreement with the momentum theorem of classical electromagnetic theory, that any thrust produced is far below practically useful levels. Hence within classical electrodynamics, there is little hope of detecting any low level motion that cannot be explained by interactions with surrounding structural steel and the Earth's magnetic field.

Introduction

This paper describes the attempt to measure the thrust of the "Non-Linear Electromagnetic Propulsion System" (NEMPS), patent no. 5,142,861, (Ref. 1) and described at the 31st Joint Propulsion Conference (Refs. 2-5). The device supposedly generates a mechanical force when electric current is sent through it. Such a device, if it produced more than the miniscule thrust of a photon rocket, would be a boon for deep space, perhaps, even interstellar, missions. No longer would it be necessary to carry half the mass of the mission in fuel. Just connect your electric thruster to a power source, such as a radioisotope heat source, and off you are to the nearest star!

After an attempt to acquire a thruster from the developer, we decided to build our own, using the patent drawings and other published material (Refs. 1-5) as construction guidelines. We also built our own pulse power supply, again relying on the sketchy descriptions provided in the references. Since we received no direct help from the developer, the device is not a perfect reproduction, but likely works as well. The reasons for this statement are given at the end of this paper.

Principle of Operation of the NEMPS thruster

According to the device description given in Ref. 2, "the rigid three dimensional geometric asymmetries in the loop antenna structure cause a magnetic field density gradient internal to the antenna structure along a single axis. This magnetic field density gradient then causes an imbalance in the internal magnetic-mechanical forces that normally result from the interactions of the loop antenna's internal magnetic field with the current in the conductors of the loop antenna's structure, as described by the Lorentz force law." The thruster is powered by a pulsed power supply "designed to provide the proper waveform to the antenna structure at an impedance matching the load impedance of the antenna. The rise time and shape of the input current waveform is crucial to maximizing the production of reaction thrust." However, neither the pulse parameters nor the reason for their criticality are given.

Description of Experiment

Conducting the experimental test of the claims of the NEMPS thruster turned out to present a different set of problems than was expected. Initially we thought that we would see evidence of some force being produced, and then having to eliminate any spurious or non-relevant forces, such as interaction with the earth's magnetic field, or with the structural steel of the building, or perhaps even the electrostatic precipitator effect. But we really observed no evidence of any force whatsoever. Thus we were reduced to setting an upper limit for the force produced by the thruster.

The first step in testing the NEMPS thruster was to build it. As can be seen from the drawing, (Fig. 1), and our implementation of it (Fig. 2) the device is a coaxial transmission line, the outer conductor of which blooms into a petal like arrangement. Four bundles of two conductors each lead from the petals back to the center conductor to complete the circuit. In our embodiment of the NEMPS thruster, the center conductor is a piece of copper rod, 1/4" in diameter and 30" long. The portion of the outer conductor between the input and the petals is a piece of copper pipe, $1^1/_2$" in diameter. The distance from the petals to the input is 5 $^1/_2$". The petals, there are eight of them, are made of 1/8" aluminum plate. They fan out at an angle of approximately 45 degrees to a diameter of 6", and then are parallel to the central axis for another $2^3/_4$". The four conductor bundles run parallel to the axis for 10", then back to the center conductor at an angle of 50 degrees. The mass of the thruster is approximately 1.8 kg.

The second step in testing the thruster was to provide power to it. The power is fed through a pair of 14 gauge wires, surrounded with copper braid, effectively making a high current coaxial cable.

The shape of a typical current pulse when operating into a 0.05 Ω resistive load is shown in Fig. 3. Here the pulse height is 2400 A, with rise and fall times of about 13 μs and 314 μs, respectively However, when driving the thruster via our made-up coaxial cables, the amplitude was reduced by the increased impedance to about 1200 amps peak, and the rise and fall times increased to about 20 μs and 400 μs, respectively. The pulse repetition rate was 30 pulses per second. To the best of our ability, we duplicated the pulse shape shown in Fig. 4, which is a sketch from Ref. 1.

This brings us to actually measuring the force. After considering various schemes, we decided to hang the thruster as a pendulum. This provides a low friction mount, and a convenient means for measuring the force. Any force produced by the thruster produces a displacement from its equilibrium position d=L (F/W), where L is the pendulum length, F is the force produced, and W is the thruster's weight.

In order to increase our ability to detect any motion of the thruster, a simple lens (focal length = 4") was attached to the thruster, and the beam from a small laser was passed through the lens and onto an opposite wall. The displacement of the spot on the wall, D, is related to the thruster displacement d, by the relation D = (R/f) d, where R is the distance from the lens to the wall and f is the focal length of the lens. In our case R = 9'4" and f = 4", so the magnification factor R/f = 28.

With this setup, we could estimate the upper limit for the thrust produced by the antenna. Usually there was spot displacement of perhaps a centimeter upon initial energizing of the thruster. It was not repeatable during a test session, and we attributed it to momentary stiffening of the power cable. The power supply was equipped with a switch that allowed us to apply power to the thruster in bursts. We tried to apply power at the natural frequency of the pendulum, in hope of seeing a greater displacement, but to no avail.

Thus we (generously) take the maximum observable spot displacement as 1 cm. This translates to a pendulum displacement of (10^{-2} m)/28 = $3.6\text{x}10^{-4}$ m. The length of the pendulum was 88" = 2.2 m, so the ratio d/L is ($3.6\text{x}10^{-4}$ m)/(2.2 m) = $1.6\text{x}10^{-4}$. The weight of the thruster is 1.8 kg x 9.8 ms^{-2} = 17.6 newtons, so the upper limit for the thruster force is 17.6 N x $1.6\text{x}10^{-4}$ = $2.8\text{x}10^{-3}$ N = $6.3\text{x}10^{-4}$ lbf = $1.0\text{x}10^{-2}$ ozf. This is considerably less than the force expected by the authors: 0.03 to 0.3 N at 4 amps, 28 volt dc. (Ref. 5). But, in a sense, the amount of thrust produced by this device is irrelevant to spacecraft propulsion. That is the topic of the next section.

Is There Hope for a Space Drive Within Classical Electrodynamics?

We should recognize, and the earlier the better, that there is little hope for a propulsion scheme that appears as a space reaction drive to an external inertial observer and is based only on the exceedingly well established Maxwellian electrodynamics. The heart of the matter is that classical electrodynamics and mechanics requires conservation of momentum in flat spacetime. Without the existence of an ether-like medium that could sustain volume forces, the momentum of an isolated electrodynamic system (matter plus the EM fields it generates) is strictly conserved. And of course, Maxwell's equations are incompatible with that kind of ether. Thus a scheme based on classical concepts can be at most a photon rocket.

Since space reaction schemes based just on EM fields keep being proposed, it may be worthwhile to review the derivation of the EM momentum theorem in order to appreciate its compelling nature. Taking the macroscopic view of material properties, formal manipulation of Maxwell's equations leads to the divergence relation

$$\nabla \cdot \vec{\vec{T}} = \rho \vec{E} + \vec{J} \times \vec{B} + \frac{\partial}{\partial t}(\vec{D} \times \vec{B}),$$

where

$$\vec{\vec{T}} \equiv \vec{E}\vec{D} + \vec{H}\vec{B} - \frac{1}{2}(\vec{E} \cdot \vec{D} + \vec{H} \cdot \vec{B})\vec{\vec{I}}$$

is the Maxwell stress tensor (in dyadic notation). This form of $\vec{\vec{T}}$ neglects the various internal stresses in matter, due to magneto- and electro-striction and nonuniformity of polarizabilities; however, these terms do not contribute to the volume integral of $\nabla \cdot \vec{\vec{T}}$.

Although the terms in the $\nabla \cdot \vec{\vec{T}}$ have the dimensions of force density and $\vec{F}_v \equiv \rho\vec{E} + \vec{J} \times \vec{B}$ is clearly the usual Lorentz force density on matter, nothing in the derivation requires that every term in $\nabla \cdot \vec{\vec{T}}$ be interpreted as a force density. Forcing such an interpretation on $\frac{\partial}{\partial t}(\vec{D} \times \vec{B})$ suggests the dubious notion of a force on EM fields or even space itself! It may be best to avoid such interpretations, with their ether-like notions, and to proceed with the integration leading to the momentum theorem, as per standard textbooks in electrodynamics (Ref. 6). The physical interpretation is then thrown back to well established concepts. Under the assumption that the Lorentz force is the only force on the matter in our electrodynamic system, the rate of change of its mechanical momentum is just

$$\frac{d\vec{p}}{dt} = \iiint_V \vec{F}_v \, dv,$$

where the volume of integration V encloses the system. Hence in this notation,

$$\frac{d}{dt}\left[\vec{p} + \iiint_V (\vec{D} \times \vec{B})\, dv\right] = \oiint_A \vec{\vec{T}} \cdot \hat{n}\, dA .$$

Letting the surface A of V expand in all directions, the above surface integral vanishes rigorously. To see this, observe that the nonradiative components of the fields decay faster than 1/r with distance, thus contributing terms to $\vec{\vec{T}} \cdot \hat{n}$ that decay faster than $1/r^2$. And if the surface is sufficiently far away, then any radiative fields turned on at a finite time in the past have not yet reached the surface – all photons are caught within the surface and taken into account. The result is the well-known, and relativistically valid, momentum theorem:

$$\vec{p} + \iiint_\infty (\vec{D} \times \vec{B})\, dv = \text{const}.$$

The above volume integral is easily interpreted as the total momentum in the EM field and for free space, the integrand reduces to the familiar $(\vec{E} \times \vec{H})/c^2$.

This momentum conservation law clearly shows that from the point of view of classical mechanics, the validity of Maxwell's equations in flat spacetime limits the space drive to at best a photon rocket. One might try to argue such things as what is the EM momentum in matter etc., but this is at the level of 'tweaking' and not a solution to practical interstellar transport. This severe bottom line strongly suggests that for practical, globally fast mass/energy transport, one must work around the classical limitations of momentum conservation by digging into the deeper layers of spacetime structure itself – the so called "spacetime engineering". Quite likely, that will bring one to deal with the vacuum zero-point fluctuations, the so-called virtual particle pairs and possibly other elements of the support of spacetime.

Summary and conclusions

No reproducible evidence was ever seen for any thrust when current pulses of 1200 A peak and 20 μs risetime were applied to the antenna at a rate of 30 per second. The result was still null, even when bursts of these pulses were applied in synch with the period of the pendulum-like suspension of the antenna. Our experiment could detect a steady force as low as 3 mN.

The simplicity and import of the electromagnetic momentum theorem underscore the hopelessness of any space reaction scheme strictly within classical electrodynamics. This severe bottom line strongly suggests that for practical, globally fast mass/energy transport, one must work around the classical limitations of momentum conservation by digging into the deeper layers of spacetime structure itself – the so called "spacetime engineering". Quite likely, that will bring one to deal with the vacuum zero-point fluctuations, the so-called virtual particle pairs and possibly other elements of the support of spacetime.

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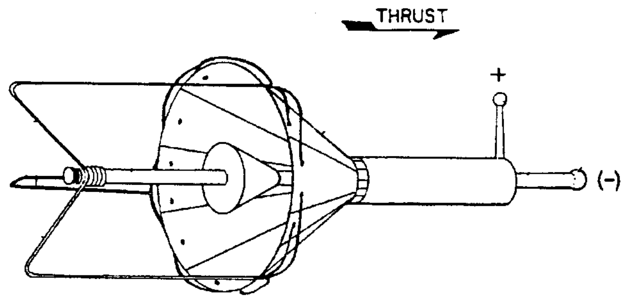

Figure 1. A typical NEMPS antenna, illustrated by R.L. Schlicher in his patent 5,142,861.

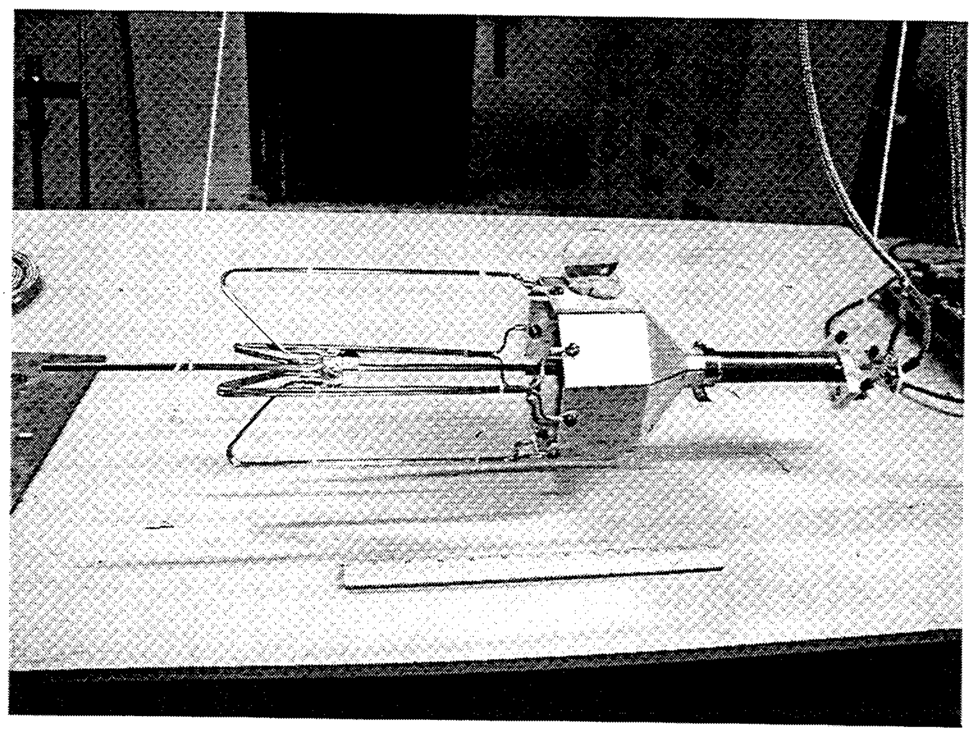

Figure 2. Our rendition of a NEMPS antenna, suspended from the ceiling. The coaxial Cable for current feed is visible on the right. Note also the lens for detection of motion by means of a laser beam.

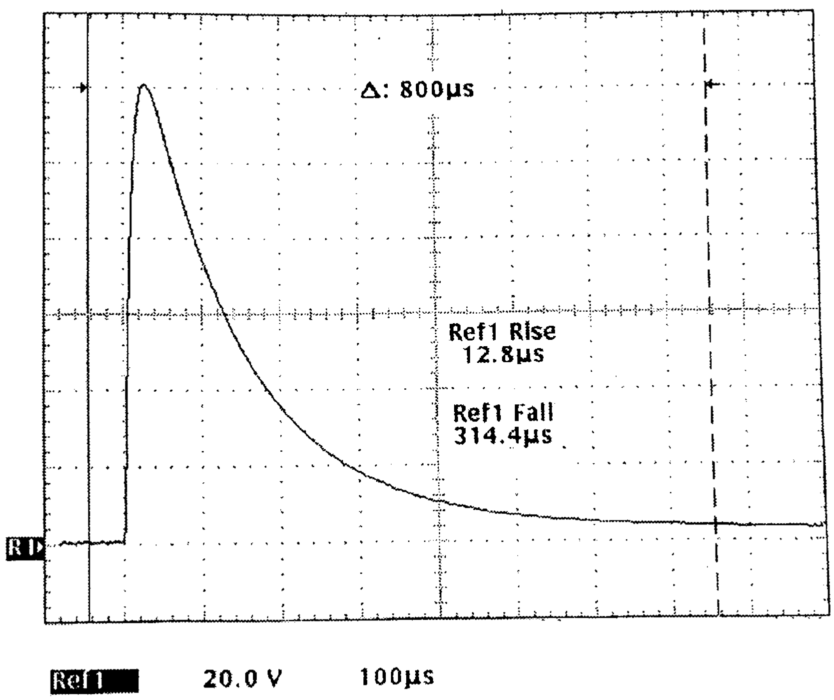

Figure 3. Typical pulse shape at maximum capability: 2400 A peak into a 0.05 Ω resistive load. When driving the thruster antenna through our coaxial cable, the pulse height was reduced to about 1200 A, at rise and fall times of about 20 µ s and 400 µ s, respectively.

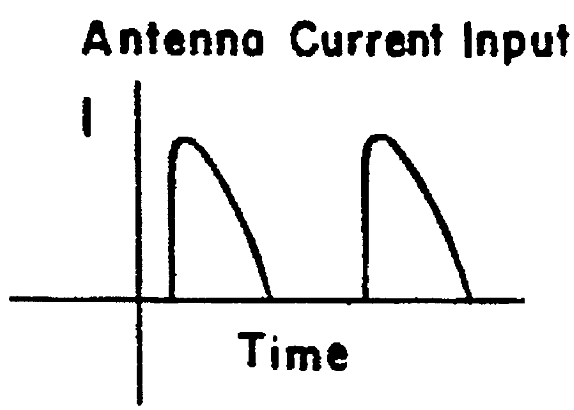

Figure 4. Current pulse shape sketch shown in the Schlicher patent. No scales are given.

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Specially Conditioned EM Radiation Research with Transmitting Toroid Antennas

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SPECIALLY CONDITIONED EM RADIATION RESEARCH WITH TRANSMITTING TOROID ANTENNAS

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Abstract

Experimental work to: (a) determine em field characteristics associated with em radiation created by alternating current flowing through toroidal coils at resonant frequencies, and (b) determine if the specially conditioned em fields associated with such radiation could cause a discernable gravity modification, is described. This experimental work was the result of collaboration between Flight Unlimited (FU) and Hathaway Consulting Services (HCS), performed at the laboratories of HCS in Toronto, Canada during a test period in 1998 and during a test period in 2000. Tested toroid configurations included: circular toroids with differing diameters and winding densities; and asymmetrical toroids for focusing em radiation into narrower and more intense beams. The toroid configurations and the AC power and instrumentation systems available at HCS limited the experimental work to the relatively low radio frequencies (400 kHz to 110 MHZ) of the electromagnetic spectrum.

INTRODUCTION

Just as airflight was not revolutionized until propeller propulsion was superceded by a new mode of impulsion (jet propulsion), so spaceflight may not be revolutionized until jet propulsion is superceded by a new mode of impulsion (field propulsion). Field propulsion would develop thrust by actions and reactions of fields instead of by combustion and expulsion of mass. And field actions and reactions that would greatly reduce propellant (the major portion of rocketship mass) and engine thrust requirements would be those that would reduce the resistance of gravity and inertia to ship acceleration.

One conceivable way of reducing the resistance of gravity and inertia is by accomplishment of a favorable coupling between those fields which underlie electromagnetism and gravity. But no significant coupling of ordinary em fields with those that give rise to gravity may be achievable because their essence is completely dissimilar. Yang (1) notes that "nonabelian" fields which probably give rise to gravity are of more intricate topology and higher internal symmetry than the "abelian U(1)" fields that underlie ordinary electromagnetism. In this respect, Barrett (2, 3) has identified two ways of transforming ordinary em fields into specially conditioned em fields of nonabelian form and higher than U(1) symmetry. One identified way of creating such fields is modulating the polarization of em wave energy emitted from microwave or laser transmitters. Such polarization modulation creates em fields of nonabelian form and SU(2) symmetry within beams of radiated power that can be focused into very narrow beams of very high energy density. Thus an experiment to detect possible gravity modifications within narrow polarization modulated laser beams has been submitted to the NASA Breakthrough Propulsion Physics (BPP) program. This experiment is described in (4).

Another way of transforming ordinary em fields into specially conditioned em fields of nonabelian form and SU(2) symmetry is with toroidal coils through which alternating current is flowing at resonant frequencies. Barrett (3) shows that such specially conditioned em radiation includes - not only electric and magnetic field energy - but A Vector potential field energy as well. Barrett predicts that A Vector field intensity maximizes at discreet resonant frequencies. Thus, if an A Vector potential field underlies the essence of gravitation, gravity modification might be possible in the vicinity of toroids transmitting at such frequencies.

Fabrication and testing costs were significant for polarization modulated laser beams. However, they were found to be relatively modest for toroidal coils configured for operation in the lower (radio-frequency) range of the em spectrum. Thus a cooperation between Hathaway Consulting Services (HCS) and Flight Unlimited (FU) was established to: test Barrett's hypotheses as to specially conditioned em radiation emitted from toroidal coils; and to determine if gravity modification could occur within such radiation. Probability of gravity modification by radio frequency radiation from inexpensive toroids was deemed to be very low. But it was hoped that the tests would reveal interesting electromagnetic phenomenon and extend our knowledge of electromagnetics.

TRANSMITTING TOROID ANTENNAS

EM wave propagation by transmitting toroid antennas has been examined by various investigators for more than a decade. Examples are U.S. Patent No. 4,751,515 awarded to Corum for an "electrically small, efficient electromagnetic structure that may be used as an antenna or waveguide probe" and U.S. Patent No. 5,442,369 awarded to Van Voorhies et al. for an antenna that "has windings that are contra wound in segments on a toroid form and that have opposed currents on selected segments". In this respect, Barrett (4) has shown that specially conditioned em fields of SU(2) symmetry and nonabelian form can be created by transmitting toroid antennas - as in Figure 1.

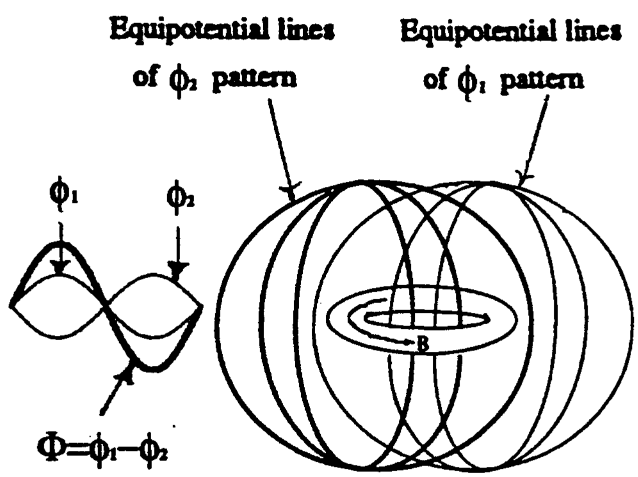


Fig. 1 – A Vector Potential Patterns

The magnetic and electric fields which encompass a transmitting toroid are accompanied by A Vector potential fields, and the alternating current flow produces overlapping A Vector potential patterns which encircle the toroid ring, as shown in Figure 1. These A Vector patterns combine into "phase factor" waves which represent disturbances in A Vector potential. The maximum disturbance in A Vector potential occurs as phase factor wave intensity peaks at the resonant frequencies where A Vector potential patterns are exactly out-of-phase, and a predicted pattern of these disturbances is shown in Figure 2.

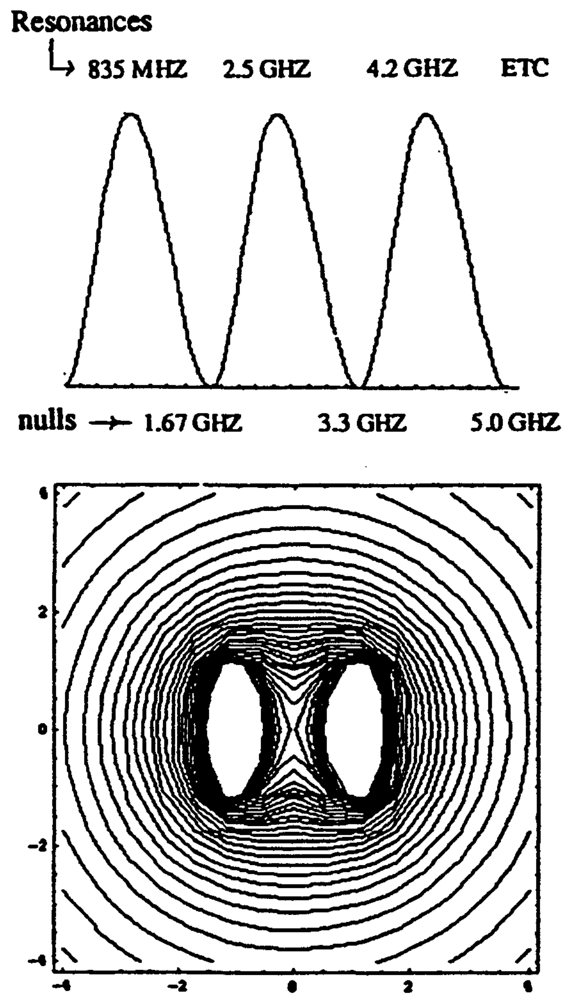


Fig. 2 – "Phase Factor" Wave Patterns

Resonant frequencies are determined by the shape and dimensions of the toroid, and by the propagating direction and speed of the alternating electric current thru its windings. And, if an A Vector potential field underlies the essence of gravitation, the probability of gravity modification in the toroid vicinity would be highest at resonant frequencies.

INITIAL TOROID EXPERIMENTS

Initial experimental work involved: (a) fabrication of transmitting toroid antennas that, according to (4), should emanate specially conditioned em radiation; and testing of the toroids at low power levels at the laboratories of HCS in Toronto. The general goals of this initial work, which was performed on March 6 and 7 during 1998, were: perfection of techniques for fabricating toroidal coils, detection of resonant phenomenon indicative of A Vector potential resonances with such coils; and identification of problems associated with operating toroidal coils over wide frequency ranges and at significant power levels.

Most of the goals of the initial work were achieved. Toroid antennas with conventional and caduceus windings were successfully fabricated, and although no instrumentation (such as Josephson Junction arrays) were available for directly detecting A Vector fields, measured resonances (reversals in phase and amplification of signal strength) were in good agreement, as indicated in Figure 3, with Barrett's predictions predicated on occurrence of A Vector fields. Heat generated by current flow within the relatively thin windings of the toroids and their relatively fragile styrofoam interiors limited input power to less than 100 watts in the initial experiments. This identified the need for thicker wires and stronger structures for higher toroid power and temperature.

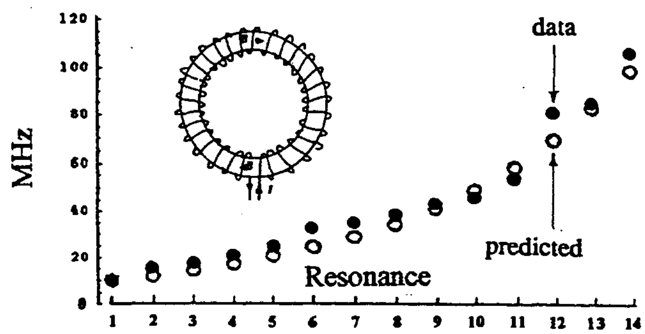


Fig. 3 – Correlation of Theory and Experiment

FOLLOW-ON TOROID EXPERIMENTS

Because results of the initial toroid experiments were somewhat encouraging, it was decided to have a follow-on experimental program, which included toroids configured for much higher power levels, at HCS between June 9 and June 15, 2000. It included: (a) signal phase/amplitude tests to precisely determine the resonant frequency characteristics of each different transmitting toroid configuration; (b) magnetic field measurements to map em field intensity in the vicinity of each toroid; (c) propagation characteristics of toroid radiation; and (d) limited gravitometer testing to search for a gravitational disturbance at a one location near one of the transmitting toroids.

Toroid Configurations Tested

To our knowledge, transmitting toroid antennas built and tested by most other investigators have been designed for communication purposes - with wires loosely wound (widely separated) around the toroid's ring in order to maximize far field intensity and range. By contrast, our tested toroids were "tightly wound" to maximize near-field intensity for possible gravity modification - not far field range for communication. Our tested toroids were "contra-wound" in a caduceus pattern to allow 2 types of modulation. One, in which current flowed in opposite directions in crossing wires, resulted in an "opposing" or "bucking" mode which caused opposing magnetic fields that cancel themselves along the toroid ring centerline. The other, in which current flowed in the same direction - resulted in an "adding" mode. Figure 4 shows the 4 different toroid configurations that were tested during the follow-on experimental program.

The loosely-wound toroid (upper left) was built for comparing its near-field intensity with that of the tightly wound toroid (lower left). Both toroids had similar cross sections (approximately 4.0 cm) and the same outer diameters (21cm) and wire size (No. 20). The greater winding density of the tightly wound toroid (350/333 inner/outer turns vs 26/25 inner/outer turns) resulted in greater near-field intensity for a given input power. The toroid in the upper right was configured with a larger outer diameter (31 cm.) than the lower left one and No. 20 wire size but its cross-section is the same. The larger diameter resulted in more windings (398/384 inner/outer turns of No. 14 wire). And the "tear drop" shaped toroid (lower right) was configured to focus radiation into more intense and elongated beams. Its length, breadth and thickness was 26.5, 18.0, 2.5 cm. It had a hole diameter of 7.3 cm; and 95/88 inner/outer turns of No. 14 wire. And, because of their stronger structure (hard maple wood) and larger wire diameter, the tear drop and larger diameter toroids could withstand the heating associated with 1.0 KW of radiated em power.

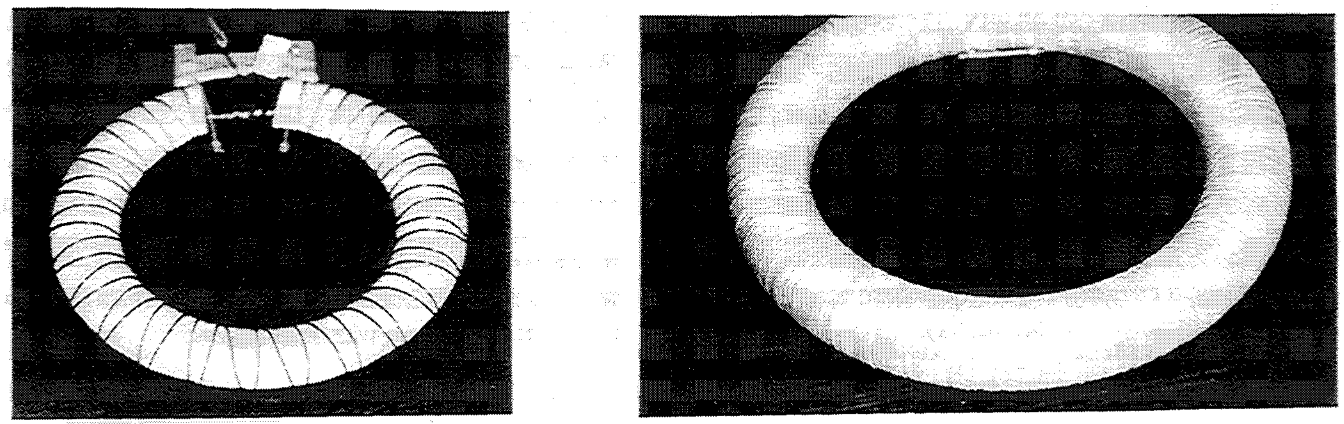
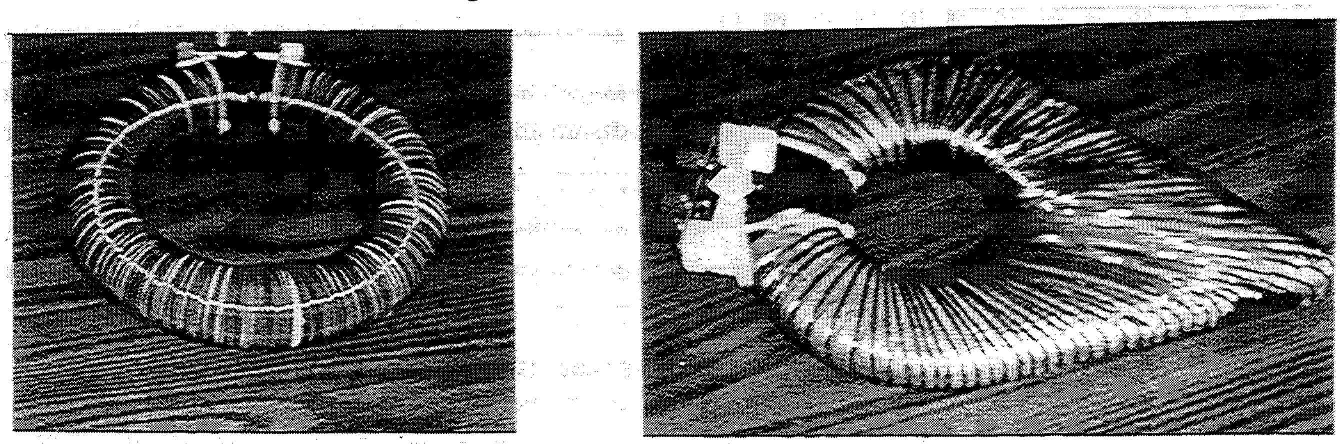


Fig. 4 – Toroid Configurations Tested



As in the first test series, resonant conditions (revealed by reversal in signal phase and rise in signal amplitude) were searched for at all ac frequencies between 400 KHZ and 110 MHZ. This was done for each toroid configuration for current opposing and current adding modes of operation. Equipment used for the resonance sweeps was an HP 4193 vector impedance analyzer. Figure 5 shows part of the test set-up for detecting resonant modes for each toroid configuration and each operating mode.

Although resonances were detected throughout almost the entire 400 KHZ to 110 MHZ frequency spectrum available at HCS, toroid radiation of significant power was only achievable in the 1.0 to 20 MHZ range. Resonant frequencies selected for measuring field characteristics of each toroid were therefore within this range. Selected resonant frequencies for the large diameter toroid were 2.36 and 17.30 MHZ for current-adding and current-opposing modes of operation, while those for the medium diameter toroid were 2.36 and 18.30 MHZ. Selected resonant frequencies for the tear drop toroid was 5.66 and 3.94 MHZ for current-adding and current-opposing, while the current-opposing, resonant frequency selected for the loosely wound toroid was 19.70 MHZ.

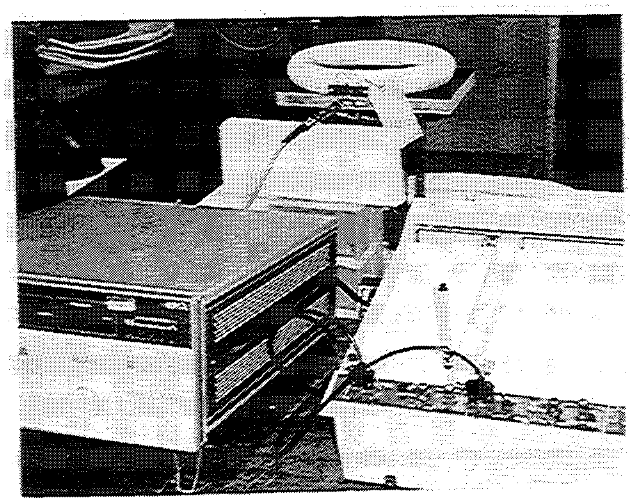


Fig. 5 – Resonance Sweep Set-Up

Toroid Field Intensity Measurements

Magnetic field intensity was measured out to 50 cm from each toroid center, and along the upper and lower surface of each toroid as well. For an applied power of 10W, the magnetic field component of each toroid's radiation was measured by a small magnetic pick-up coil shown in Figure 6, which converted the actual magnetic field intensity into an equivalent electric field strength (in micro volts per meter).

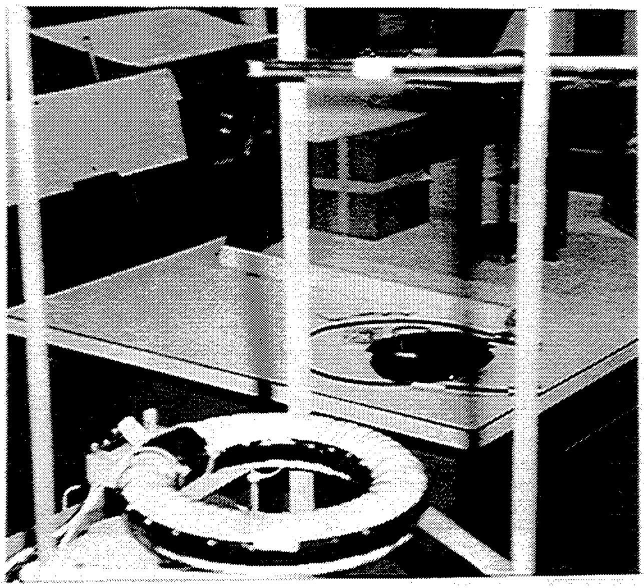


Fig. 6 – Magnetic Field Probe

Variation of the large diameter toroid's field strength with range (out to 10 meters) was measured with various types of antennas outside the HCS facility with the test set up as indicated in Figure 7. Data consistent with expected near-field signal strength variation with range was measured when the toroid was radiating in a current-adding resonant mode at 1.20 MHZ. But measurements in a current-opposing resonant mode were anomalous - in that no significant signal strength variation with range was detected.

Search For Gravity Modification

Final toroid testing activity was searching for gravitational field modifications within the specially conditioned em field regions surrounding toroids radiating at resonant frequencies. Gravitational disturbances were searched for with a "Prospector Model 420" gravitometer, manufactured by W. Sodin Ltd, which is capable of detecting changes as small as one-millionth of one percent of ambient gravity. This gravitometer's stainless steel shell and aluminum base does not provide complete magnetic field shielding. But its dewar-enclosed, all-quartz mechanical balance system is not influenced by ordinary em emissions. Unfortunately, preceding test activities took longer than expected, leaving time to search for gravity modification for only one of the toroids (the large diameter one) at only one location with respect to the gravitometer. The limited time remaining also required a very rapid toroid/gravitometer set up. This was achieved by the positioning shown in Figure 8.

Fig. 7 –Toroid Range Test Set-Up

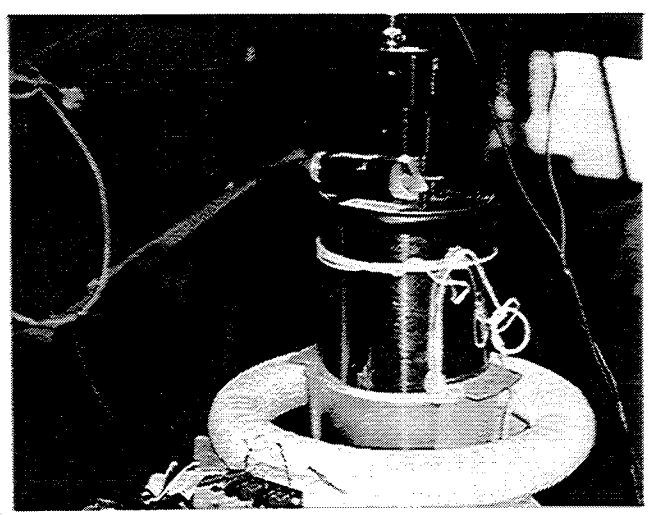


Fig. 8 – Toroid/Gravitometer Set-Up

TOROID TESTING RESULTS

Resonant frequencies between 400 KHZ and 110 MHZ were obtained for each toroid. And, for the purposes of mapping magnetic field intensity in each toroid's vicinity, one resonant frequency was selected for each operating mode for each toroid. Field intensity out to 10 m from the large diameter toroid was also measured together with the influences of magnetically shielded structures on its field intensity. Finally, the effect of large diameter toroid field intensity on gravity modification was explored. The results of these efforts are summarized in the following sections.

Toroid Resonance Determination

Resonant frequencies for current-adding and current-opposing operating modes were obtained for each toroid. Figures 9 and 10 show examples of the resonances obtained for the large diameter and tear-drop toroids throughout the 400 KHZ-110 MHZ radio frequency spectrum available at HCS.

Toroid Field Patterns

Magnetic field intensity variation with radial distance for the 3 circular toroids was similar with intensity maximizing near the inner surface of each toroid's ring. And, as would be expected, intensity diminished rapidly with increasing distance above and outside each toroid. Figure 11a and 11b show no definite trend with respect to the influence of toroid diameter. Higher magnetic field intensity is achieved by the smaller diameter toroid in a current-opposing mode of operation while higher magnetic field intensity is achieved by the larger diameter toroid in a current-aiding mode. Figure 11c shows a definite trend - with increased windings over a given toroid geometry resulting in increased magnetic field intensity.

Significant focusing of the electromagnetic energy radiated from the asymmetrical "tear drop" toroid was accomplished. Figure 11d shows that magnetic field intensity is enormously greater at given distances forward of the center of the toroid's hole than for the same distances aft of the hole center. Figure 9d also shows a top and front view of the tear drop toroid field pattern for a given magnetic field intensity. It is seen that more electromagnetic energy is focused into the forward direction than into the aft or side directions and that the toroids flattened shape (its reduced thickness) causes less radiation to be dissipated in directions transverse to the toroid plane.

One interesting discovery was formation, in the circumferential direction, of standing em waves along the upper and lower surfaces of transmitting toroids. No standing wave measurements were made on the loosely wound toroid. However, numbers of magnetic field peaks and nodes measured circumferentially on the top and bottom surfaces of the other circular toroids were 8 for the medium diameter toroid and 10 for the large diameter one. And at least 6 magnetic field peaks and nodes were measured on the top and bottom surface of the tear drop toroid.

Attenuation of Toroid Field Intensity

Field strength attenuation with range from the center of the large diameter toroid is shown in Figure 12. It was about as expected when radiating at a resonant frequency of 1.2 MHZ in a current adding mode of operation, with a steep signal drop (greater than $(1/r)^3$ out to about 1.0 meter and with an expected near-field $(1/r)^2$ variation between 3 and 10 meters from the toroid. But measurements made with the toroid radiating at a resonant frequency of 17.3 MHZ in a current opposing mode indicated no significant variation in signal strength at distances 3 to 10 meters from the toroid. After continual measurements and re-measurements with various types of antennas, we have no definitive explanation for lack of signal strength reduction with increasing range - other than the possibility of operating slightly off resonance and a significant drop in signal strength.

Additional anomalous behavior may also have been observed for the large-diameter toroid - in that almost identical signal strength was measured at a given location and distance from the toroid when radiating in free space and when radiating from within a magnetically shielded (mu metal) enclosure. These results are considered inconclusive because stray signals were detected from power supply leads which were outside the shielded enclosure. Since measured signals were almost identical for both shielded and un-shielded conditions, and since it is unlikely that almost all of the measured free space signal was from the power supply leads, it is conceivable that some of the toroid's em wave energy was propagated through the magnetically shielded mu metal walls.

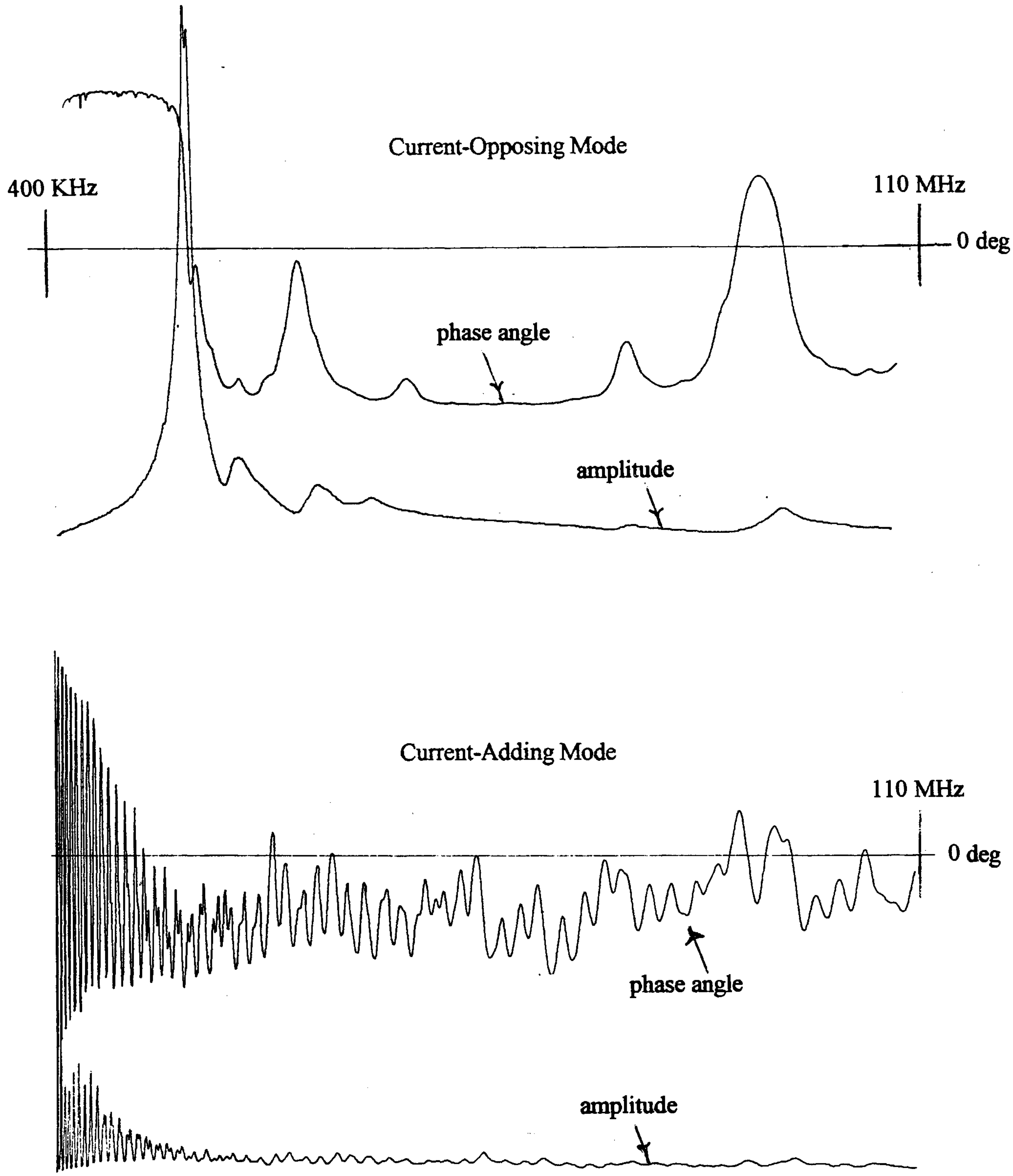


Fig. 9 – Resonances for Large Diameter Toroid

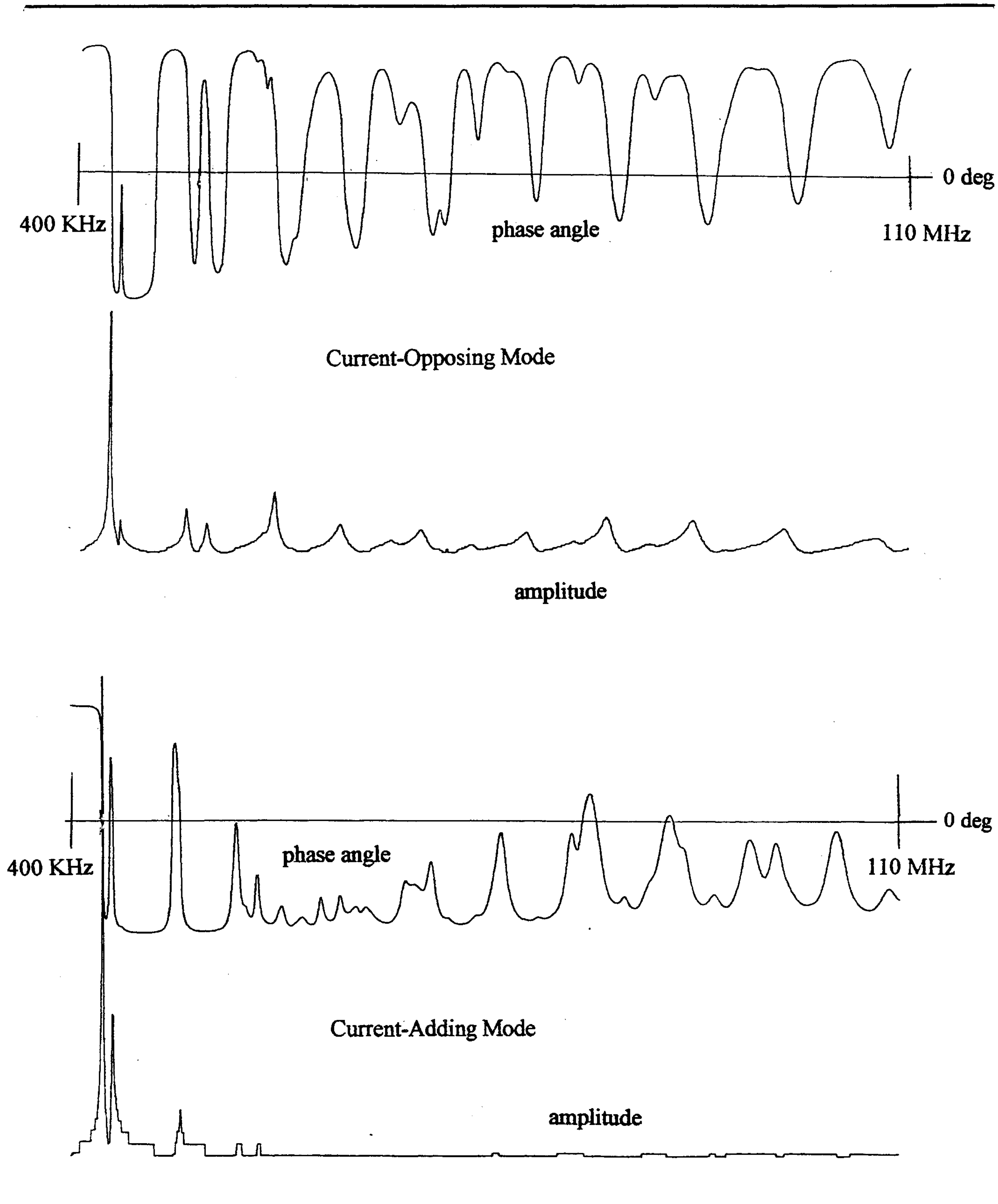
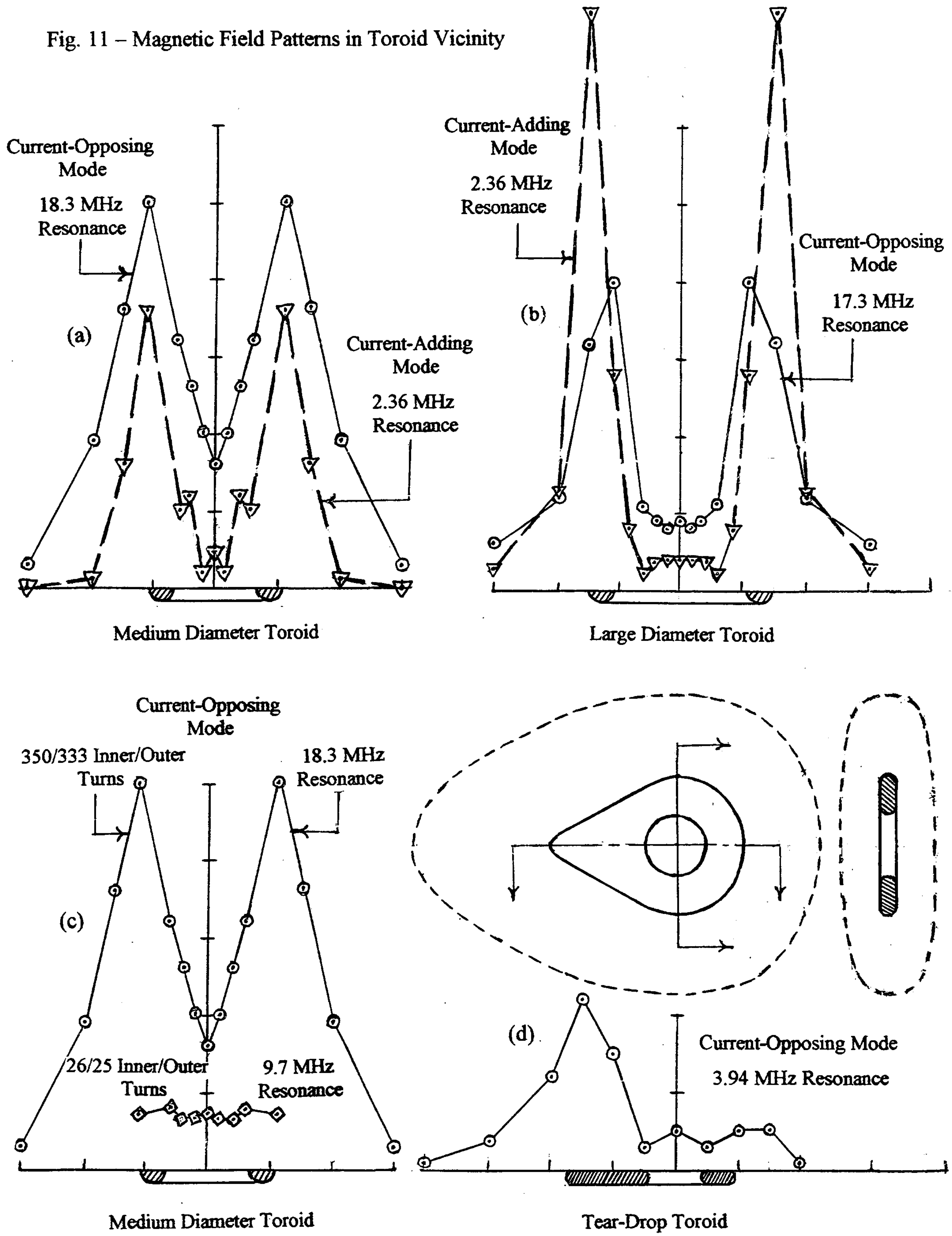


Fig. 10 – Resonances for "Tear-Drop" Toroid

Fig. 11 – Magnetic Field Patterns in Toroid Vicinity



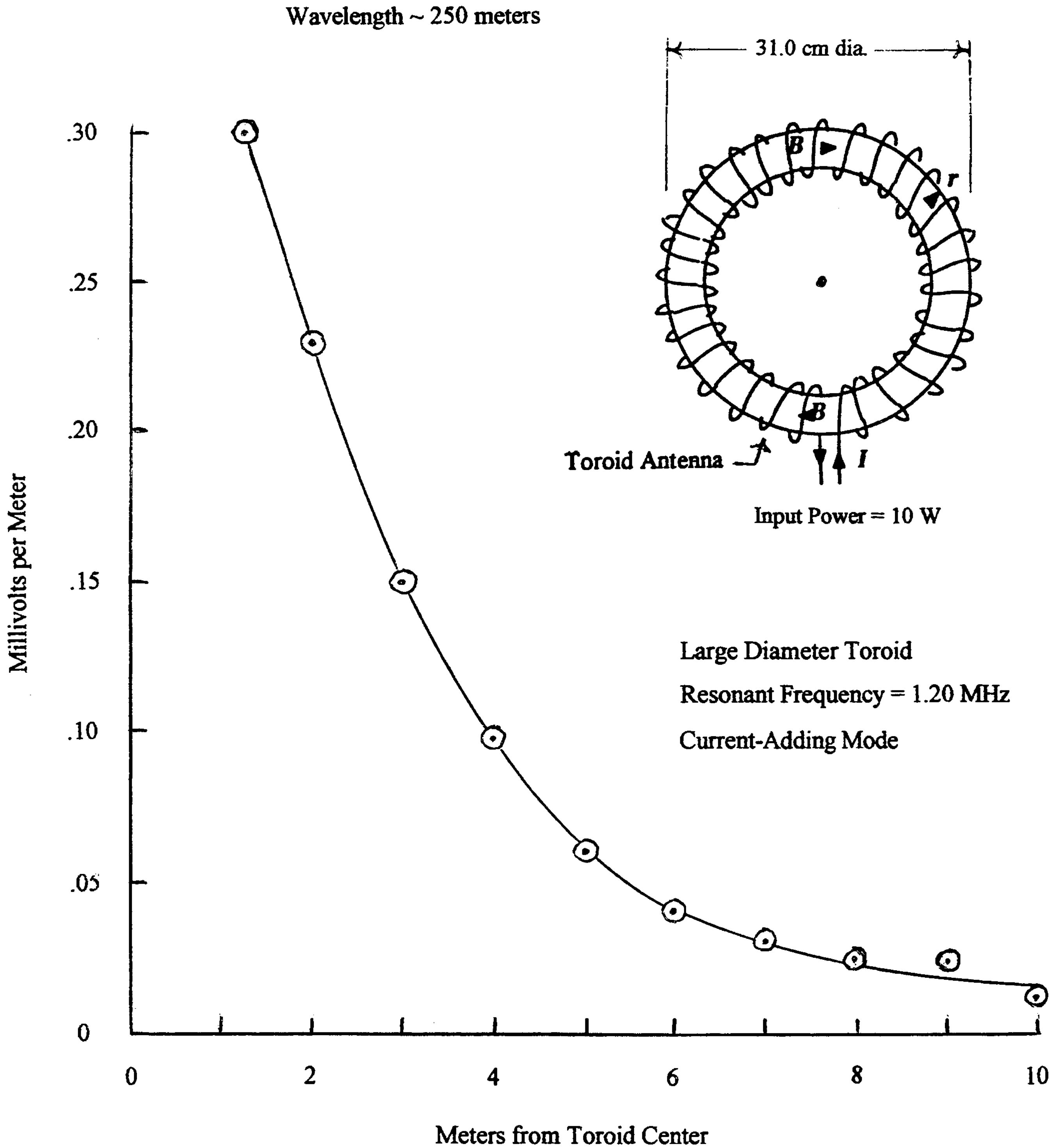


Fig. 12 - Attenuation of Toroid Signal with Range

Search for Gravity Modification

The possibility of gravity modification in the vicinity of transmitting toroid antennas was briefly investigated by use of the Prospector 420 gravitometer and the large diameter toroid radiating up to 0.5 KW of average power at the resonant frequencies associated with current-aiding and current-opposing operation modes. For these powers and operating modes, no discernable gravity modification was detected for the single toroid/gravitometer positioning that time allowed.

As previously mentioned, time limitations required a rapid toroid/gravitometer test set-up which resulted in the gravitational mass being located in a magnetic field region whose intensity was subsequently found to be much less than magnetic field intensity existing in other locations. For the current opposing mode of operation, measured magnetic field intensity at the gravitometer test mass location was only about 15 percent of the maximum intensity measured near the toroids inner diameter. And toroid magnetic field intensity at the gravitometer test mass location was only about 2 percent of the maximum measured magnetic field intensity for the current-adding mode.

One conceivable reason for non-discernable gravity modification is, of course, 5 to 50 times less em field intensity at the single location probed by the gravitometer, as compared to locations of maximum intensity. But another reason could be dissimilarity in field topologies associated with toroid em emanations and gravity. And still another reason could be enormous possible differences in the frequencies and wavelengths characterizing gravitational fields and those that characterize electromagnetic fields created by transmitting toroid antennas.

SUMMARY AND CONCLUSIONS

Although interesting phenomenon are associated with em fields created by alternating current flowing at resonant frequencies through toroid coils, no discernable gravity modification (caused by coupling of these fields with those of gravity) was detected.

Interesting electromagnetic phenomenon were: (a) standing em waves along toroid surfaces; (b) em wave energy focused into more intense beams by asymmetrical toroid shapes; and (c) possibly, em wave propagation through magnetically shielded enclosures. There might have been increased probability of detecting a discernable gravity modification if there had been time for gravitometer measurements in regions where toroid field strength was much greater.

The possibility of anomalous wave propagation should be confirmed or refuted by re-testing the large diameter toroid within a magnetically shielded structure that encloses both the toroid and its power leads.

Zero gravity modification within the radio frequency em fields surrounding transmitting toroid antennas should be confirmed by a gravitometer search throughout the entire vicinity of the large diameter toroid.

ACKNOWLEDGMENTS

This experimental work was motivated by theoretical work by Dr. Terence Barrett with respect to specially conditioned em fields created by transmitting toroid antennas. Dr. Barrett also contributed useful suggestions as to recommended toroid configurations and test procedures. The most recent experimental work was conducted with the considerable assistance of Mr. Blair Cleveland, who was intimately involved in every aspect of the test preparations conduction and data gathering portions of this work.

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An Experimental Investigation of the Physical Effects in a Dynamic Magnetic System

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37th AIAA/ASME/SAE/ASEE
Joint Propulsion Conference and Exhibit
8-11 July 2001
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AN EXPERIMENTAL INVESTIGATION OF THE PHYSICAL EFFECTS IN A DYNAMIC MAGNETIC SYSTEM.

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Abstract

In the current paper the results of experimental research of magnetic-gravity effects are presented. Anomalous magnetic and thermal changes within a radius of 15 meters from the researched device were measured as well.
PACS: 41.20.-q; 44.60.+k; 76.50.+q

Introduction

We have experimentally studied the physical effects in a system based on rotating permanent magnets [1]. Below we describe the technology of manufacture, assembly, and the results of testing this experimental setup, which is referred to as the converter.

Received effects:

- Generation of mechanical energy in a self-governing mode of operations;
- Change of weight of the converter;
- Formation of a local magnetic and temperature fields as concentric cylinders around converter.

Description of the Experimental Setup

The basic difficulty arises in choosing the materials and maintaining the necessary magnetic pattern ("imprinting") on the plate and roller surfaces. To simplify the technology we decided to use a one-ring design with one-ring plate (stator) and one set of rollers (rotor). It is obvious, that it was necessary to strengthen the rollers on a rotor by the bearings and balance the rollers well. In the suggested design, air bearings were used which provided the minimum losses due to friction.

From the available description [1] it was not clear how it is possible to make and magnetize the stator with a diameter of about one meter. In order to make the stator from separate magnetized segments executed with rare earth magnets with the residual induction of 1T, the segments were magnetized in a usual way by discharging a capacitor-battery energizer through a coil. Afterwards the segments were assembled and glued together in a special iron armature, which reduced magnetic energy.

To manufacture the stator 110 kg of rare earth magnets were used. To manufacture the rotor 115 kg of that material was used. High-frequency field magnetization was not applied. It was decided to replace imprinting technology described in [1] with cross-magnetic inserts having a flux vector directed at 90 degrees to the primary magnetization vector of the stator and rollers. For these cross-inserts the modified rare earth magnets with residual magnetization of 1.2 T and coercive force a little bit greater than in a base material were used. Fig.1 and Fig.2 show the joint arrangement of stator 1 and rotor, made up of rollers 2, and a way of their mutual gearing or sprocketing by means of cross magnetic inserts 19. Between the stator and roller surfaces air gap δ of 1 mm is maintained.

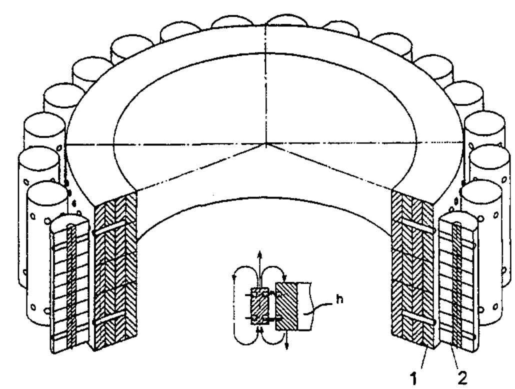

Fig. 1. Variant of one-ring converter.

No layered structure was used except a continuous copper foil of 0.8 mm thickness, in which the stator and rollers was wrapped up. This foil had a direct electrical contact to magnets of the stator and rollers. Distance between the inserts in rollers is equal to distance between the inserts on the stator. In other words $t_1 = t_2$ on a Fig.2.

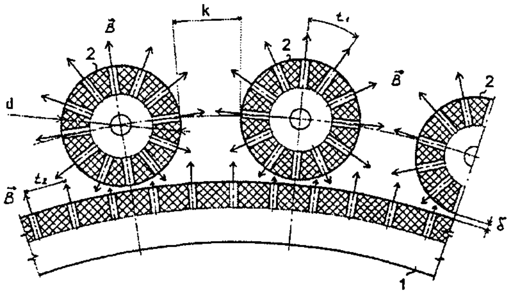

Fig.2. Sprocket effect of magnetic stator and roller inserts.

The ratio of parameters of the stator 1 and the rotor 2 on Fig.2 is chosen so that the relation of stator diameter D to the roller diameter d is an integer equal to or greater than 12. Choosing such ratio allowed us to achieve a resonant mode between elements of a working body of the device.

The elements of magnetic system were assembled in a uniform design on an aluminum platform. Fig.3 displays the general view of the platform with the one-ring converter. This platform was supplied with springs, shock absorbers and had a possibility of moving vertically on three supports. The possible vertical displacement was 10mm and the induction meter 14 was used for measuring this displacement. Thus, the instantaneous change of platform weight was defined during the experiment in real time. Gross weight of the platform with magnetic system in an initial condition was 350 kg.

The stator 1 was mounted motionlessly and the rollers 2 were assembled on a mobile common rotor - separator 3, which is connected with the basic shaft 4 of the converter. Through this shaft the rotary moment was transferred. The basic shaft by the means of friction muff 5 was connected to a starting engine 6, which accelerated rotor of the converter up to a mode of self-sustained rotation. An ordinary DC electrodynamics generator 7 also was connected to the basic shaft as a main loading of the converter. Adjacent to the rotor, electromagnetic inductors 8 with open cores 9 were located.

The magnetic rollers 2 crossed the open cores of inductors and closed the magnetic flux circuit through electromagnetic inductors 8, inducing an electromotive force in them, which acted directly on an auxiliary active load 10 - a set of incandescent lamps with total active power of 1 kW. The electromagnetic inductors 8 were equipped with an electrical drive 11 on supports 12. Driven coils were used for smooth stabilization of the rotor rpm. The speed of the rotor also could be adjusted by changing the main loading 10.

To study influence of high voltage on characteristics of the converter, a system for radial electrical polarization was mounted. On a periphery of rotor the ring electrodes 13 were set between the electromagnetic inductors 8 and had an air gap of 10 mm with the rollers 2. The electrodes are connected to a high-voltage source; the positive potential was connected to the stator, and the negative - to the polarization electrodes. The polarizing voltage was adjusted in a range of 0-20 kV. In the experiments, a constant value of 20 kV was used.

In case of emergency braking, a friction disk from the ordinary car braking system was mounted on a basic shaft of the rotor. The electrodynamics generator 7 was connected to an ordinary passive resistive load through a set of switches guaranteeing a step connection to the load from 1 kW to 10 kW - a set of ten ordinary electric water heaters.

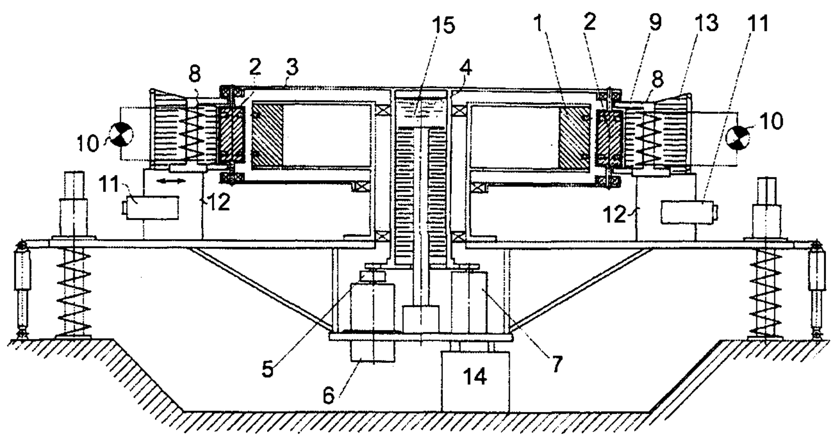

Fig.3. The general view of the converter and its platform.

Converter under testing had in its inner core the oil friction generator of thermal energy 15 intended for directing a superfluous power (more than 10 kW) into the thermo-exchange contour. But since the real output power of the converter in experiment has not exceeded 7 kW, the oil friction thermal generator was not used.

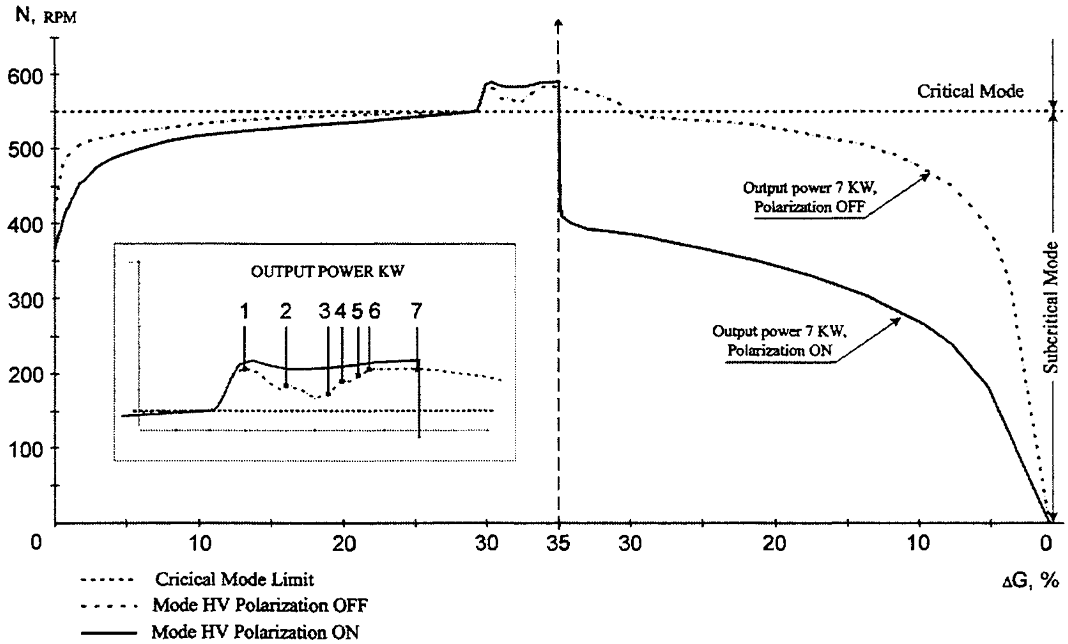

Fig.4. A diagram illustrating various operation regimes of the converter, -G, +G changes in weight of the platform vs. rpm

Experimental results

The magnetic converter was mounted in a laboratory room on three concrete supports at a ground level. The ceiling height of lab room was 3 meter. A common working area of the laboratory was about 100 sq. meters. Besides a presence of an iron-concrete ceiling in the immediate proximity from the magnetic system there was a generator and electric motor, which contained tens of kilos of iron and could potentially deform the field structures.

The device was started by the electric motor, which accelerated rpm of the rotor. The revolutions were smoothly increased up to the moment the ammeter included in a circuit of the electric motor begin to show zero or a negative value of consumed current. The negative value indicated a presence of back current. This back current was detected at approximately 550 rpm under clockwise rotation. The displacement meter 14 starts to detect the change in weight of the whole installation at 200 rpm. Afterwards, the electric motor is completely disconnected by the electromagnetic muff and an ordinary electrodynamics generator is connected to the switchable 10 kW resistive load. The converter rotor continues self-accelerating and approaches the critical regime of 550 rpm when the weight of the whole installation quickly changes.

In addition to dependence on a speed of rotation, the common weight of device depends from output power on the load and from applied polarizing voltage as well. As seen on Fig.4, under maximum output power is equal to 6-7 kW the change of weight ΔG of the whole platform (total weight is about 350 kg), reaches 35 % of the weight in an initial condition G_i. Applying a load of more than 7 kW results in a gradual decrease of rotation speed and an exit from self-sustained mode (right sides of the curves on Fig.4 for a 7 kW loading).

The net weight G_n of the platform can be controlled by applying high voltage to polarization ring electrodes located at a distance of 10 mm from external surfaces of the rollers. Under a high 20 kV voltage (electrodes have a negative polarity) the increase of tapped power of the basic generator more than 6 kW does not influence ΔG if rotation speed is kept above 400 rpm. "Tightening" of this effect is observed as well as the effect of hysteresis on ΔG at rotation of a rotor on a clockwise and counter-clockwise (a kind of "residual induction"). The experimental diagrams given on Fig.4 illustrate the +G and –G changes in weight of the converter vs. rotor rpm. The effect of a local change of the platform weight is reversible, relative to the direction of rotor revolution, and has the same hysteresis. A clockwise rotation causes the critical regime to occur in area of 550 rpm and a propulsion force against the direction of gravitation vector is created. Correspondingly, a counter-clockwise rotation causes the critical mode to occur the in area of 600 rpm and a force in the direction of gravitation vector is created.

The difference in approach to a critical regime of 50 - 60 rpm was observed. It is necessary to mention that the most interesting region are situated above the critical area of 550 rpm, but due to of a number of circumstances the implementation of such research was not possible. Probably, there are also other resonant modes appropriate to higher rpm of a rotor and to the significant levels of useful loading and weight changing. Proceeding from the theoretical assumptions, the dependence of tapped mechanical energy from the parameters of magnetic system of the converter and rpm of a rotor has a non-linear character and the received effects are not optimum. From this point of view, the revealing of a maximal output power, of maximal change of weight and converter resource represents a large practical and scientific interest. In tested sample of the converter the using of higher rpm was inadmissible because of unsufficient mechanical durability of the magnetic system, which has been stuck together from separate pieces.

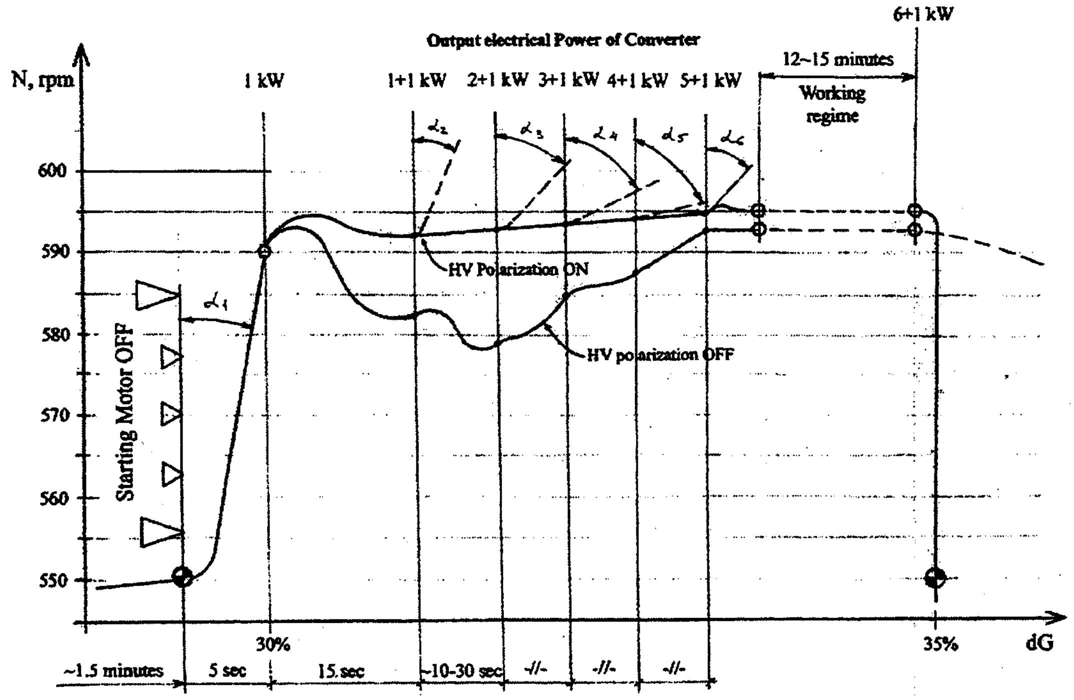

Fig.5 Diagrams of rotor accelerating and loading of the converter.

On Fig.5 the dependence of total weight of whole installation and its output power directed into active loading from rpm of a rotor of the converter is explained in detail. The diagrams are constructed for a case of HV polarization ON (top diagram) and HV polarization OFF (bottom diagram). The time from starting of the engine up to a mode of self-sustaining of the converter at the rotation of a rotor clockwise approximately is equal 1.5 minutes. Power of starting DC engine was about of 2 kW and reduction on a shaft of the converter was equal 1/10. At achievement of a critical mode (550 rpm.) the change of gross weight of a platform already achieves +/-30% from G_i. Under transition to resonant mode the revolutions with the large acceleration have increases up to 590 rpm and weight has changes up to + /-35% from G_i. This point on the diagram begins at once after a critical point (inclination of a curve α_1). At achievement of 590 rpm the first stage of active loading 1 kW is connected to the electrodynamics generator. The revolutions have a sharply reducing and ΔG also is changing. As soon as the revolutions begin to grow again, the second switchable loading is connected and rotor rpm are stabilized at a level of 590-595 rpm. ΔG continues to change. The increasing of switchable loading occurs by steps on 1 kW up to total power of 6 kW. All intervals are equal approximately of 10-30 sec. Afterwards the short-term increasing of revolutions and then the full stabilization of the 6 kW output during of 12-15 min was observed.

More than 50 launches of the converter with an absolute repeatability within three months were carried out. It is necessary to note that revolutions will grow with acceleration shown on Fig.5 by angles $\alpha_1 \ldots \alpha_5$, if do not switch on the next step of loading to the generator at rpm increasing. For returning to a previous rpm mode it is necessary to switch on a twice more loading.

The words above concern a mode with switched ON a high voltage polarization of 20 kV, "plus" is on a grounded stator. Without polarization voltage (lower curve on Fig.5) the diagram is approximately the same, but is well indicated the more soft character of a loading and faster changing of weight of a platform due to decreasing of rpm.

Other interesting effect is corona discharges, which was observed at the work of the converter in a dark room. At this, around the converter rotor a blue-pink glowing luminescence and a characteristic ozone smell were noticed. On Fig.6 the cloud of ionization covers area of the stator and rotor and is having accordingly a toroidal form.

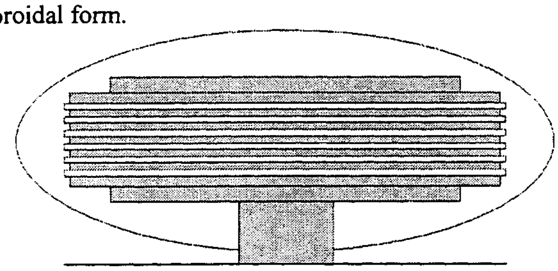

Fig.6. Corona discharges around the converter.

On a background of luminescence glowing on the roller surfaces, we distinguished a separate «wave picture». A number of more vigorous strips of discharges around the rollers were observed. These discharges were of a white-yellow color but the characteristic sound for arc discharges was not audible. There were not noticed any erosive damages by arc discharges on surfaces of the stator and the rollers as well.

One more effect previously not mentioned anywhere was observed - the vertical concentric magnetic "walls" around the installation. We noticed and measured a permanent magnetic field around the converter within a radius of 15 meters. For this magnetic field measurement a Russian made magnetometer F4354/1 was used. Magnetometer had a Hall-effect sensor in a copper shielding. The zones of increased intensity of a magnetic flux 0.05 T, located concentrically from the center of the installation were detected. The direction of the magnetic field vector in these walls coincided with direction of magnetic field vector of rollers. The structure of these zones was like the Bessel function of zero order of two arguments. No any magnetic fields were registered between these zones by portable magnetometer. The layers of increased intensity were distributed practically without losses up to a distance of about 15 meters from a center of the converter and had a quick decreasing at a border of this zone. The thickness of each layer was approximately of 5 - 6 cm the border of each layer was very sharp. The distance between layers was about of 50 - 80 cm where the upper value is seen when moving from center of the converter. A stable picture of this field was observed as well as at a height of 6 m above the installation (on the second floor above the lab). Above the second floor, measurements were not carried out. The similar picture was observed and outside of a room of laboratory, directly in the street, on the ground. The concentric walls were strictly vertical and no had appreciable distortions. The Fig.7 illustrates the schematic placing of the converter in a room of laboratory and arrangement of concentric magnetic and thermal fields around the installation.

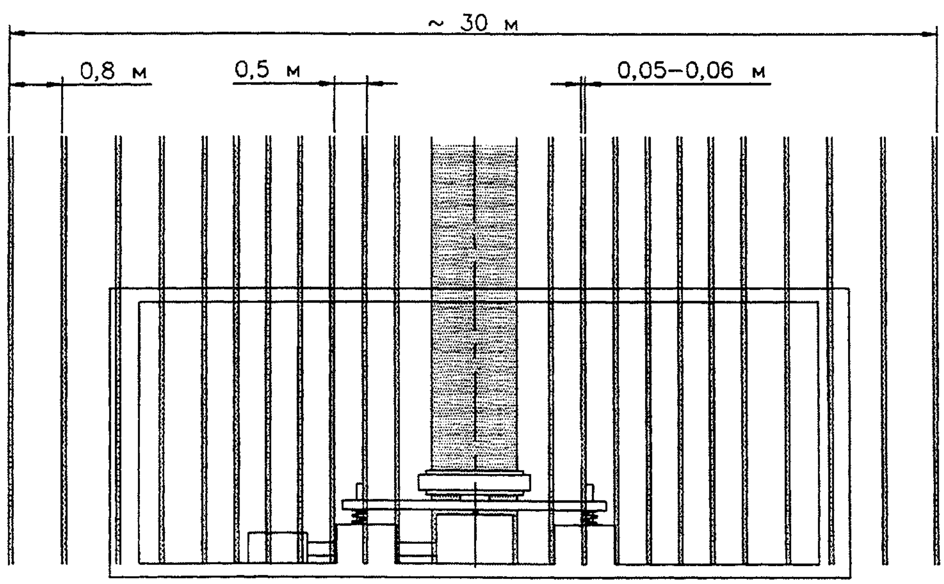

Fig.7. Schematic placing of the converter and field patterns in lab room.

An anomalous decrease of temperature in a vicinity of the converter was also found. While the common temperature background in laboratory was + 22°C (±2°C) the stable fall of temperature of 6-8°C was noticed. The same phenomenon was observed in concentric vertical magnetic walls as well as. The measurements of temperature inside the magnetic walls were carried out by an ordinary alcohol thermometer with an inertia of indication about 1.5 min. Inside the magnetic walls the temperature changes can even be distinctly observed by hand. When the hand is placed into this magnetic wall the cold is felt at once. A similar thermal picture was observed at height above the installation, i.e. on a second floor of the laboratory as well as despite the steel-reinforced concrete blocks of a ceiling and also on an open air outside of the laboratory.

Concentric magnetic walls and accompanied thermal effects begin to appear approximately from 200 rpm and have a linearly increasing with speeding up of revolutions up to a critical regime. The measurements above 600 rpm were not made because of fear of destruction of magnetic system. On Fig.8 the curve of intensity of magnetic field in mT and change of temperature in Celsius degrees due to rpm changing is represented.

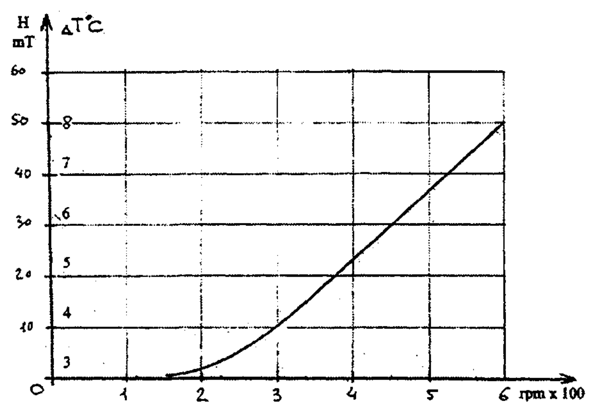

Fig.8. The dependence of intensity of magnetic field and changes of temperature vs. rotor rpm of the converter.

Discussion

All the results we obtained are extremely unusual and require some theoretical explanation. Some theoretical approaches and phenomenological descriptions can be found in our book [2]. Unfortunately, interpretation of these results within the framework of conventional physical theory cannot explain all observed phenomena especially the change of weight. We can interpret change of weight as a local change of gravitation or as some propulsion force like a propeller work in air. Only a role of a propeller the magnetic system is playing, and a role of air - the quantum environment - ether filled with a "dark matter and energy". Direct experiment, which would has confirming the presence of a propulsion force was not performed, but in any case both interpretations of the weight change do not correspond to the modern physics paradigm.

In conclusion we would like to emphasize that issues of biological influence and especially effects of unknown radiation around of the converter were not considered at all. Our own experience allows us to do only cautious assumption that the short-term stay (dozen minutes) in a working zone of the converter with fixed output power of 6 kW remains without observed consequences for exposed persons.

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RAPID SPACETIME TRANSPORT AND MACHIAN MASS FLUCTUATIONS: THEORY AND EXPERIMENT

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ABSTRACT

The various schemes for achieving rapid spacetime transport currently in circulation are briefly reviewed, and then the methods based on Machian mass fluctuations are considered. Results of experimental work designed to detect a negative-definite Machian mass fluctuation expected on the basis of simple theory are then reported. They suggest that such mass fluctuations may in fact occur and have sufficient magnitude to be engineerable into practical devices.

INTRODUCTION

It is a commonplace that although rockets may serve to cover interplanetary distances, however inefficiently, when interstellar voyages in some reasonable fraction of a human lifetime are considered, conventional rocketry comes up seriously wanting. The fundamental problem, simply put, is: How does one accelerate a reasonable payload to some significant fraction of the speed of light in short order without having to lug idiotically large amounts of propellant along to push off of? Only a moment's reflection is required to see that, short of creating "wormhole" spacetime shortcuts with "exotic matter", there are two distinct, but related ways to tackle this problem. One is to reduce the mass of the payload. The other is to find some means of producing an accelerating force on the payload without lugging along all the propellant required by rockets. Conventional approaches of considerable ingenuity have been devised in both cases. But they still fall far short of the technical requirements for serious interstellar travel. The question then is, do the laws of physics allow the invention of unconventional spacecraft – starships – equal to interstellar voyages?

In the matter of payload reduction, ideally one would want to render the mass of a ship and its contents as nearly equal to zero as possible. Were that possible, only minute forces would be needed to accelerate the ship to near lightspeed. Is this possible? To answer this question we must understand the cause of the inertial properties of matter; that is, why things push back on us when we try to accelerate them.

At the moment three putative causes of inertia are advocated. There are those who simply assert that inertia is an innate property of matter that is independent of all external circumstances. Others believe that inertia results from the local action of quantum mechanical "zero point" fluctuations of the electromagnetic field (and perhaps other non-gravitational fields) on things that are accelerated. And some are convinced that inertial reaction forces are caused by the gravitational action of chiefly distant matter in the universe. If inertia is an inalterable, innate property of matter, then the only way to reduce the mass of a ship is to find and collect some "exotic" matter (with negative mass) to offset the positive mass of the payload. Such material, naturally occurring, has yet to be discovered in nature.

Compelling reasons exist to set aside the electromagnetic "zero point" fluctuations explanation of inertia.[1, 2] But even were that not the case, it seems exceedingly unlikely that any means could ever be found to suppress zero point fluctuations over the volume of a starship (thereby supposedly rendering it essentially inertialess). The Casimir effect, often cited in connection with these arguments, does point up the fundamental problem here. It is the low frequency part of the vacuum fluctuation spectrum that is suppressed by material objects in close proximity that produces this effect. But, alas, it is the high frequency part of the fluctuation spectrum that is chiefly responsible for the induction of the vast bulk of inertia in this scheme. (We note here that Lorentz invariance requires that the spectral energy density of the vacuum fluctuations increase with the cube of the frequency thereof.)

Taking inertial forces to be due to the gravitational action of chiefly distant matter in the universe – as is the case in general relativity theory – leads to two possible approaches. One is to find some means of "shielding" the bulk of the starship from the action of the gravity field of the distant matter. This might be done either passively by finding a "gravity insulator" – H.G. Wells' cavorite that is – or actively by devising some apparatus that generates a gravity field that can

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be used to "null" the gravity field produced by distant matter. Cavorite, like naturally occurring "exotic" matter, remains to be discovered. Several active methods have been explored – notably spinning superconducting disks in suitable electromagnetic fields – so far to no avail. One troubling aspect of these schemes is that they do not follow from the widely accepted form of the laws of physics. And they usually lead to violations of fundamental conservation laws. The second approach consists of finding a way, within the structure of accepted physical laws, to transiently induce a reduced mass state, perhaps fleetingly even an "exotic" mass state, in normal matter by some technically feasible means. This may sound quite implausible, but it turns out that there may be a way to do this. We discuss this, along with some experimental results, below.

Turning to the issue of generating accelerating forces, we see that the fundamental problem, irrespective of the propulsion system being considered, is how to push off of the distant matter in the universe. In conventional rocket propulsion systems, this is achieved by using propellant as an intermediary. That is, when we push on propellant, the gravitational action of the chiefly distant matter in the universe causes the propellant to push back on us, causing an accelerating force on us. Since the prodigious propellant payload is the chief impediment to interstellar voyages, one might want to devise a propulsion scheme that involves, ideally at least, no lugged propellant whatsoever. In conventional systems this requirement translates to either "harvesting" propellant locally as one goes along, using beamed energy from home with "sails", or finding a way to couple locally to cosmic fields of one sort or another. None of these seem very realistic at present.

Alas, the strictly propellantless "breakthrough" schemes appear even less realistic than the conventional proposals, for they all seem to violate some fundamental, well-tested physical principle. Usually, but not always, it is the conservation of momentum that bites the vacuum. The best known of these schemes involves the aforementioned spinning superconducting disks. In these circumstances, however, the action of the disks is not interpreted as shielding or attenuating the gravitational field of other objects. Rather, it is regarded as generating a directed "gravity or inertia-like" field analogous to the "gravitomagnetic" field generated by spinning objects that is predicted by general relativity, but magnified in intensity by many orders of magnitude. This putative force does not act on the generating apparatus *per se*. But aimed at distant matter in the direction one wants to go, it acts on the distant matter and a mutual force is established that accelerates the spacecraft. No violation of momentum conservation is necessarily involved here. But there is no compelling reason to believe that when electric charge carriers form Cooper pairs (as they do in the superconducting state), no matter how they are acted upon by external electro-magnetic fields, they acquire the magical ability to create from nothing the gargantuan "inertialike" fields claimed.

Another strictly propellantless propulsion scheme is based on the observation that electromagnetic circuits can be arranged so that they appear to generate self-forces – that is, forces appear in one part of the circuit that seem not to be cancelled by equal and opposite forces anywhere else in the circuit. Perhaps the best example of this type of scheme is the "Slepian" approach advocated by Dering, Corum, and several of their associates.[3] The issue of "hidden momentum" in electrical circuits has a long history. Suffice it to say that the generation of a net force in an isolated electrical circuit capable of accelerating a spacecraft is a very dubious proposition. To be relativistically (and empirically) correct, the laws of electrodynamics must be invariant under the group of infinitesimal Lorentz transformations. This invariance insures that energy and momentum are conserved in isolated systems. Aside from the obvious violation of the conservation of momentum involved in the Slepian scheme, simple physical common sense suggests that it is not reasonable. Accelerations take place with respect to the distant matter in the universe. The likelihood that one could produce accelerations without coupling to that matter in any way is, on its face, pretty preposterous. Well, unless the quantum vacuum couples to the distant matter and can be acted upon in some way by the local electromagnetic fields. But that is not what is claimed in "Slepian" systems.

Should it prove possible to produce transient variations in the masses of material objects, another means of propulsion may be achievable. Here some local mass is used as a propellant. But instead of simply ejecting the matter once and for all, after it has been "ejected" one operates on it to reduce its mass so that it can be recovered without canceling the momentum imparted to the craft when it was earlier ejected. It may then be ejected again in its normal state, and the mass-reduced recovery repeated. And this cycle may be repeated over and over again, *ad nauseam*. This may sound like having one's cake and eating it too. But when we keep in mind that the gravity/inertia field couples the craft (and recycled propellant) to the distant matter in the universe, it is apparent that such a scheme merely amounts to producing a directed momentum flux in the gravitational/inertial field by the local manipulations matter. One may object that the propagating "momenergy" in the gravitational field produced by any reasonable concentration of local matter is so ridiculously small that even were such a scheme in principle possible, surely it would be utterly impractical. But one ignores, in this view, the fact that inertial reaction forces are gravitational actions too. *They are enormous and instantaneous.* So there is hope, should it prove possible to induce a transient mass-reduced state in some propellant without violating the laws of physics.

THEORY

When inertial reaction forces are viewed as arising from the action of a locally Lorentz-invariant field (as they actually are), one finds that objects subjected to accelerations by external forces undergo changes in their restmasses during the accelerations.[4, 5, 6, 7] This is a consequence of the four-vector nature of the reaction forces – and the fields producing them – and the four-dimensionality of the divergence operator that is applied to the four-field strength to obtain an expression for the local charge density. To see how this works, consider an object accelerated by an external force. An (equal and opposite) inertial reaction force arises in the object owing to the action of the local "inertial" field on it.[8, 9] The field strength experienced by the object is just the inertial reaction four-force divided by the mass of the object. To get the local source density of this field we apply the four-dimensional generalization of Gauss's divergence theorem. Taking account of the fact that the field is irrotational (so the three-force can be expressed as the gradient of a scalar potential) and translating charges into charge densities (as is customary in constructing field equations), this yields:

$$\nabla^2\phi - (\phi/\rho_o c^2)(\partial^2 E_o/\partial t^2) - (\phi/\rho_o c^2)^2(\partial E_o/\partial t)^2 = 4\pi G\rho_o, \qquad (1)$$

where ϕ is the scalar potential of the inertial field, ρ_o the local restmass density, c the vacuum speed of light, E_o the local rest-energy density ($=\rho_o c^2$), and G Newton's universal gravitational constant.

To transform this equation into a field equation of standard form we need merely note that inertial reaction forces are gravitational forces (Mach's principle) and that since this is true, in this approximation we have that $\phi = c^2$ and the rest energy density E_o can be written as $E_o = \rho_o\phi$ [$= \rho_o c^2$]. Using this expression for E_o in Equation (1) and rearranging we obtain:

$$\nabla.\phi - (1/c^2)(\partial^2\phi/\partial t^2) = \Box\phi = 4\pi G\rho_o + (\phi/\rho_o c^2)(\partial^2\rho_o/\partial t^2) - (\phi/\rho_o c^2)^2(\partial\rho_o/\partial t)^2 - c^{-4}(\partial\phi/\partial t)^2, \qquad (2)$$

the inhomogeneous relativistically invariant wave equation for the scalar gravitational potential. Note the transient matter source terms on the RHS of Equation (2). *If real*, they may make rapid spacetime transport technically feasible.

If we ignore $- c^{-4}(\partial\phi/\partial t)^2$ since it is always minuscule given its c^{-4} coefficient (not compensated for by any factor of ϕ in the numerator, as in the other terms), and extract a factor $4\pi G$, we may write the total, time-dependent matter density as:

$$\rho(t) \approx \rho_o + (1/4\pi G)[(\phi/\rho_o c^2)(\partial^2\rho_o/\partial t^2) - (\phi/\rho_o c^2)^2(\partial\rho_o/\partial t)^2]. \qquad (3)$$

The first time-dependent term – $(1/4\pi G)[(\phi/\rho_o c^2)(\partial^2\rho_o/\partial t^2)]$ – can be both positive and negative when ρ_o undergoes periodic fluctuations. When effects arising from this term are convolved with a second periodic force in an object, this restmass fluctuation can lead to the production of stationary forces.[10, 11, 7] One merely pushes on an object made more massive by this mass fluctuation, and then pulls it back when it is in a mass-reduced state to achieve a net accelerating force. For this reason we call this the "impulse engine" term in Equations (2) and (3). The second time-dependent term, unlike the first, is always negative, because the negative sign of the term is unaffected by the sign of ρ_o since it appears exclusively in quadratic factors: $- (1/4\pi G)[(\phi/\rho_o c^2)^2(\partial\rho_o/\partial t)^2]$. This term, if it can be made large, holds out the possibility of the transient formation of "exotic" matter – matter with negative mass – the material needed to achieve the most extreme types of rapid spacetime transport by the warping of spacetime. We resist the temptation to assign this term a romantic label, calling it merely the "negative mass" term in Equations (2) and (3).

As with the impulse engine term, when mass fluctuations driven by the negative mass term in some object are convolved with a second periodic force, stationary forces can be produced. So both the impulse engine and negative mass effect terms hold out the promise of realizable propellantless propulsion. *Note that the transient mass terms in Equation (3) are enormous in comparison with, for example, the mass changes that occur from simply changing the energy content of some region in space-time. This is a consequence of the transient terms being "magnified" by the factor* $(\phi/\rho_o c^2)$ *coefficients where, as a consequence of Mach's principle,* $\phi/c^2 \approx 1$, *rather than being a very small number as one might otherwise expect when* ϕ *has a value of the scale normally assumed* (*that is,* $<< c^2$).

The stationary forces that result from both of these terms depend on the relative phase of the driven mass fluctuation and the second applied force. Their periodicities, as a function of the relative phase, however, are not the same because for a driven periodic fluctuation in ρ_o, the resulting contributions from the impulse engine term have the same periodicity as the driving signal, but the negative mass term varies at twice the frequency of the driving signal because the time derivative of the driving signal is squared. Were the negative mass term much smaller than the impulse engine term, as simple calculations can lead one to believe, this would not be a matter of much moment. But, in fact, the negative mass term is comparable to the impulse engine term, as can be seen by inserting the *ansatz* $\rho_o = \rho cos(\omega t)$ into Equation (2) and computing the resulting expressions for the impulse engine and negative mass terms. This procedure does not yield an exact solution of this non-linear equation. But it does reveal that the amplitudes of the two factors in the square brackets are the same, to factors of order unity at any rate. Thus, should Machian mass fluctuations actually occur, one should be prepared to see evidence of the negative mass term in any system sensitive enough to detect the impulse engine term.

Before turning to a discussion of experiments designed to test for the presence of the mass fluctuations just described, we mention general considerations that should inform experiments. We ask first, where might one expect to see the sort of mass fluctuations predicted by Equation (2) above? Since this equation follows from the consideration of the action of an accelerating force on matter, plainly some material must be present that is accelerated. The fact that the transient terms in Equation (2) both involve derivatives of the local rest matter density, ρ_o, indicates that the local *rest* energy density, E_o [$=\rho_o/c^2$], must also be changing. Evidently, the largest Machian mass fluctuation effects are to be expected in materials where, viewed at the microscopic level, the application of external electromagnetic fields produce large accelerations accompanied by rapid changes in stored internal energy. Thus, for example, if mass fluctuations are to be driven in dielectric mater-ials in capacitors, then one will want to use material with the highest possible dielectric con-stant. In particular, ferroelectric substances. It is worth noting, nonetheless, that if the vacuum can be truly regarded as a polar-izable substance, then one may expect to drive mass fluctuations in the vacuum itself. And should such fluctuations be convolved with an appropriate periodic force, stationary forces like those expected in material media should be producible. Such forces, however, would be minuscule in comparison with those pro-duced in materials with large dielectric constants. An experiment designed to test for mass fluctuations in the vacuum would make a good test of the reality of the "polarizable vacuum" model of GRT that has recently been elaborated by Puthoff.[12]

EXPERIMENT

Results of experiments designed to detect Machian mass fluctuations have already been report-ed.[4, 5, 11, 13, 7] We report here current results of the ongoing experimental program underway at California State University, Fullerton (CSUF). For the past several years that program was focused on the detection of stationary forces in stacks of lead-zirconium-titanate [PZT] crystals driven with voltage signals of several hundred volts at several tens of kHz using sensitive torsion pendula, started by JFW and TLM in the course of TLM's graduate work. (See refs. 7, 13, and especially 14 for the details of this work.) Since fall 2000 the focus of this work has changed to an updated version of early experimental tests of mass fluctuations by looking for the effect as a weight fluctuation with force transducers.[4, 5] *Approaching experimental detection of any mass fluctuation effect in this way has the great merit that only the mass fluctuation* per se *is detected (as a weight fluctuation), so all issues relating to the production of stationary forces by signals of several frequencies and phases are set aside (unless such forces are inadvertently produced by convolution of harmonics of the fundamental signal with mass fluctuations driven thereby that might affect weight determinations).*

The search we are conducting for Machian mass/weight fluctuations, for the moment at least, utilizes PZT stacks like that shown in Figure 1. This PZT stack consists of ten crystal disks, 1.91 cm in diameter made of EDO Ceramics EC-65 material

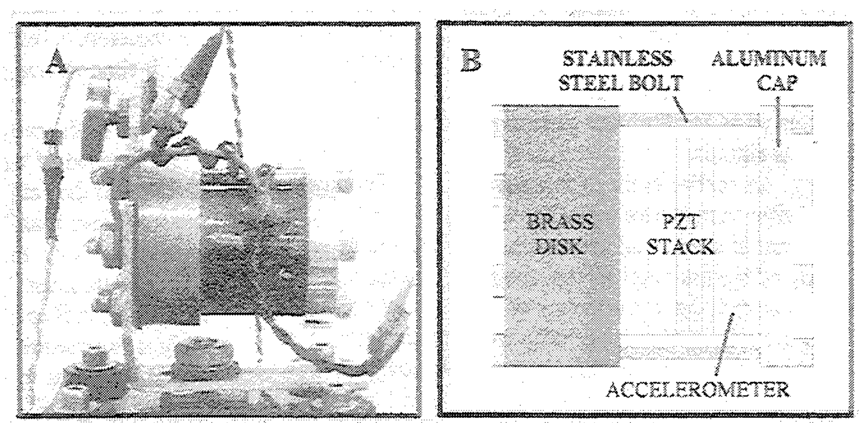

Figure 1: A. A picture of the device mounted on the force transducer. The thermisor and accelerometer connection are at the top center-left. B. A schematic diagram of the device showing the arrangement of the crystals and accelerometer in the PZT stack.

epoxied together along with suitable electrodes between the crystals. The stack is clamped by six machine screws between an aluminum cap and a 0.95 cm thick brass disk. The pair of crystal disks closest to the brass disk are 0.31 cm thick, whereas all but two of the crystal disks at the other end of the stack are 0.15 cm thick. Thinner disks, with higher stored energy for a given applied voltage to the stack, are used in the part of the stack near the aluminum cap where the largest accelerations, and thus predicted effects, are expected. Two of the crystal disks are very thin, being only 0.03 cm thick. This pair of crystals was placed between the two pairs of 0.15 cm thick crystals closest to the aluminum cap and independently wired so that they could be used as an accelerometer to monitor the behavior of this part of the PZT stack.

An aluminum mounting bracket is attached to the brass disk as shown in Figure 1. Note the thin rubber pad that isolates the bracket from the brass disk. This was included to suppress the transmission of vibration from the stack assembly to the weight sensors used. This pad, however, contributes significantly to improved performance of the stack. It also suppresses the flow of heat into the bracket. The temperature of the stack assembly is monitored with a thermistor glued onto a small aluminum ear that is also attached (without a rubber pad) to the brass disk. (This aluminum ear also carries a bimetallic strip thermometer used in earlier work.)

Two different weight detection systems were developed for the work we report here. The chief system employed a Unimeasure U-80 position sensor configured as a load cell. (See Figure 2.) This type of weigh system has been used extensively by one of us (JFW) in earlier work, and the chief results reported here were obtained with this system. The second weight detection system, still under development at the time of this writing, utilizes optical detection of displacements driven in a cantilevered beam to detect any weight fluctuations. (The optical/cantilevered beam technique was suggested by John Cramer.) Both weigh systems were enclosed in clear acrylic containers that were pumped down to vacua typically of 10 to 20 microns so as to eliminate several potential sources of spurious signals.

In earlier work of this sort, arrays of capacitors, rather than stacks of PZTs, were driven by a voltage signal at about half the mechanical resonance frequency of the load cell so that the mass fluctuation excited at the power frequency of the applied voltage signal would produce a periodic weight fluctuation that would be resonance amplified by mechanical properties of the load cell.[4, 5] Since the resonance frequency of the load cell was typically about 100 Hz, and the magnitude of the mass fluctuation scales with the square of the frequency of the voltage signal, only minuscule weight fluctuations could be driven at the 100 Hz frequency, and mechanical resonance amplification and signal averaging were essential to see any effect at all. Nonetheless, this seemed the only path to detection of the mass fluctuation effect open at that time, for the presence and significance of the negative mass term in Equations (2) and (3) above was not then appreciated. Confined to the impulse engine term, which time-averages to zero, no other approach seems feasible.

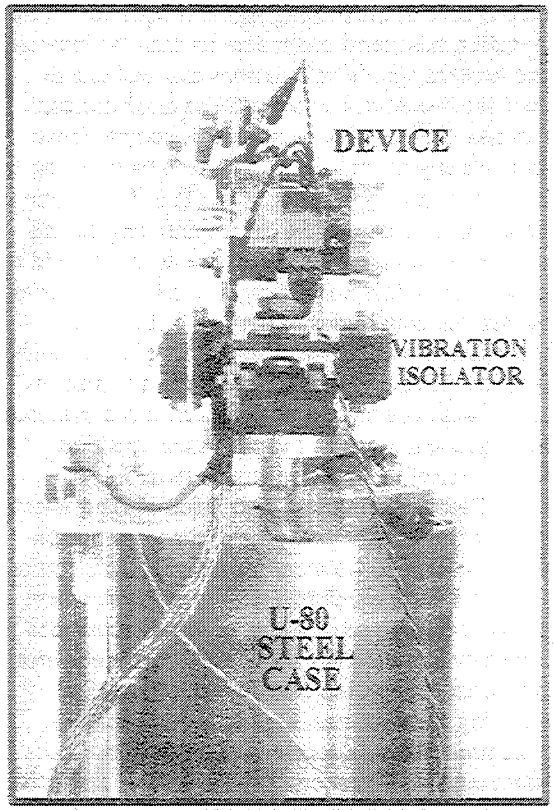

Figure 2: The device mounted on the U-80 (located in the steel shielding case) via a vibration isolator made from several layers of plastic and neoprene rubber. An accelerometer is affixed to the botton of the aluminum stage that the isolator is bolted to. The stage is stabilized against lateral motion by tensioned fine steel wires.

In the present experiments, the cantilevered beam method of weight detection is problematical because of the rather large mass of the suspended device (more than 100 grams). In order to get sufficient sensitivity, the mechanical resonance frequency of the beam must be made rather low (less than ten Hz). This makes it difficult to detect a short, transient weight fluctuation. The situation with the U-80 load cell is better, as its mechanical resonance frequency is several tens of Hz – out of the range of low frequency acoustic and seismic noise sources. Moreover, this higher resonance frequency makes it possible to follow transient weight fluctuations with durations in the 100 to 200 millisecond range. This is especially important as, since the early work was done, the importance of the negative mass term in Equations (2) and (3) has come to light. Because the effect of this term is always to reduce the mass of the object in which it is excited (being negative definite), a stationary time-averaged mass shift arising from this effect can be produced by a voltage signal of much higher frequency than the mechanical resonance frequency of the load cell. Indeed, this effect can be optimized by driving the PZT stack at one of *its* mechanical resonance frequencies (typically about 75 kHz in devices like that in Figure 1). *Since the time-average of this effect during an applied power interval will lead to a stationary weight reduction, one may simply observe any weight change directly should it be large enough.* Impulse engine term effects, by themselves, do *not* lead to such stationary weight shifts since they time-average to zero.

Mass fluctuations arising from the negative mass term, in real circumstances, if present at all, may be much smaller than ideal considerations suggest. So, should one want to excite a mechanical oscillation of the weigh system near its resonant frequency to bring out a small effect, one need only pulse the high frequency voltage signal delivered to the PZT stack at some suitable low frequency. This procedure, however, proved unnecessary, as with reasonable signal averaging an effect of the sort sought could be obtained. Instead, the frequency of the applied voltage signal was swept through a predetermined range of values to allow for the fact that changing conditions in the PZT stack might cause the frequency of peak effect to change from test to test.

The experimental protocol actually followed was to take data during an interval of several seconds. During the first and last parts of this interval no appreciable voltage signal was applied to the device being weighed. For several seconds between these quiescent periods the voltage signal was applied to the device. By frequency modulation of the signal generator used, the frequency was swept from 70 to 78 kHz during this interval. This frequency interval was chosen because it includes the fundamental mechanical resonance frequency of the PZT stack where the effect sought was expected. Even though a surprisingly large weight fluctuation near the resonance was found, because of a rather poor signal to noise ratio in the weigh signal, we found it necessary to average the data for typically 50 to 100 or more of these data cycles together in order to extract a clear, statistically significant signal.

Aside from the weigh systems *per se*, other components of the apparatus used in this experiment, indicated in Figure 3, are: a power amplifier (a DBX 150 Watt linear amplifier), a 5-to-1 toroidal stepup and isolation transformer (TRANS), voltage and current sense resistors in the high voltage secondary transformer circuit so that the voltage and current signals could be multiplied (4 QUAD MULT.) to get the instantaneous power delivered to the PZT stack, and a rectification and filtering circuit (POWER METER) so that the power could be read as a voltage in real time. Additional instrumentation allows measurement of acceleration of the PZT stack by the embedded accelerometer and the temperature of the device was recorded with the aforementioned thermistor.

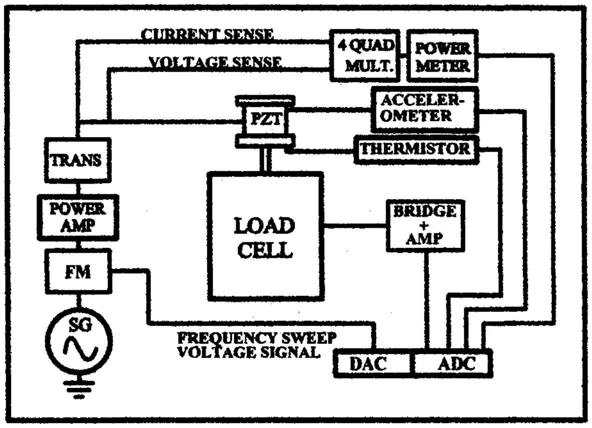

Figure 3: A schematic diagram of the chief electronic circuits used in this experiment. The DAC and ADC are computer controlled.

While the chief parts of the associated circuitry and instrumentation are displayed schematically in Figure 3, several other signal detection features are not displayed. For example, a Picoscope AD212 was also used to monitor various signals at various times. Its software provides FFT power spectrum display capability that is quite helpful for analyzing harmonics present in those signals. Toward the end of the acquisition of data for this paper it became clear that more detailed know-ledge of the thermal behavior of the device than that provided by the thermistor was desirable, so two types of non-contact infrared (IR) detection – one a simple thermo-couple device and the other an IR imaging camera – were introduced. A thermocouple vacuum gauge was used to monitor the vacuum in the vacuum vessels. Operation of the system and data acquisition and processing is computer controlled via a Canetics PCDMA data acquisition board. Data acquisition and post-acquisition data processing is done with software written specifically for that task (adapted from software used in earlier experiments).

The core apparatus in use in the load cell version of this experiment is shown in Figure 2. The weight transducer is located in the 1 cm thick steel shielding case visible in the figure. The load cell vacuum chamber is a small box about 22 cm on a side 26 cm high made of 3 cm thick acrylic plastic (not shown in Figure 2). As in earlier realizations of experiments using the U-80 load cell, *with sufficient averaging of data from individual cycles*, a mass (or weight) shift of a few milligrams could be resolved – assuming that the static calibration of the load cell with a one gram mass is applicable to signals registered in conditions where high frequency vibration is present in the PZT stack. This last assumption is open to question, for the manufacturer of the U-80 stipulates that the sensitivity of the Hall probe used changes unpredictably in the presence of significant vibration with frequencies above 1 kHz.

The obvious way to deal with this potential problem is to mount the PZT device on the weigh stage of the U-80 with high frequency vibration isolation. (Low frequency isolation is neither needed nor desirable. Indeed, hard coupling at low frequencies is required to make the weight measurements that are the objective of this experiment.) This was done in the earlier phase of this experiment by progressively introducing more and more vibration isolation components. Changes in the weight response of the U-80 disappeared before the isolator configuration seen in Figure 2 was implemented. That is, the isolator shown constitutes over-kill. Nonetheless, to be certain that appreciable high frequency vibration was not communicated to the U-80, an accelerometer (made with thin chips of PZT material) was affixed to the bottom of the weigh stage, and the weight signal was scrutinized with the Pico-scope run in power spectrum mode. Both the accelerometer signals and the power spectrum analysis of the weight signal confirmed that no significant high frequency vibration was present in the U-80 during the operation of the PZT device.

RESULTS

The chief result of this experiment is displayed in Figure 4. It shows the average of several hundred cycles of data taken in a variety of different circumstances. The data displayed is "net" data. While the actual data were being acquired, "null" data where the power to the device in each cycle was manually shut off as soon as the power was automatically activated. The average of the null data has been subtract-ed from the raw data average. In each cycle data was taken for a period of 14 "seconds" at a rate of 50 acquisitions per "second". In fact one "second" was 0.65 actual seconds, the shift having been made by the adjustment of a delay loop in the data acquisition program. Power was not applied to the device until four "seconds" into each cycle. When power was turned on, the frequency of the applied sinusoidal signal was swept from 70 kHz to 78 kHz during the ensuing six "seconds". After the power was switched off, data continued to be taken for an additional four "seconds". Three channels of data in addition to the weight sensor were acquired. One channel recorded the rectified and filtered (10 milli-second time-constant) power signal. This is displayed with the weight signal in panel A of Figure 4. Another channel recorded the rectified and filtered signal from the accelerometer embedded in the PZT stack; and yet another channel recorded the temperature measured by the thermistor epoxied to the aluminum ear bolted to the back of the brass disk on which the PZT stack was mounted. The data from these channels are displayed with the weight signal in panel B of Figure 4.

Simple inspection of Figure 4 reveals that a pronounced weight decrease occurs near 74 kHz. The magnitude of the decrease, about 60 ADC counts, corresponds to roughly 0.1 gram for a peak applied power of about 105 Watts. This is nearly the fluctuation expected on the basis of a naïve, ideal calculation based on Equation (3) above (within a factor of three or so). Note that the weight fluctuation is correlated to spikes in the power and accelerometer traces that signal the occurrence of resonant behavior in the PZT stack. Moreover, the temperature trace recorded by the thermistor shows an inflection in the heating rate that also correlates to the weight shift at 74 kHz.

The thermistor, of course, does not promptly measure the temperature of the PZT stack. Heat evolved in the PZT stack as power is applied is localized in the end of the stack where, by design, the maximum activity is induced – as can be seen in the far infrared (7.5 to 13.3 micron) image of the device

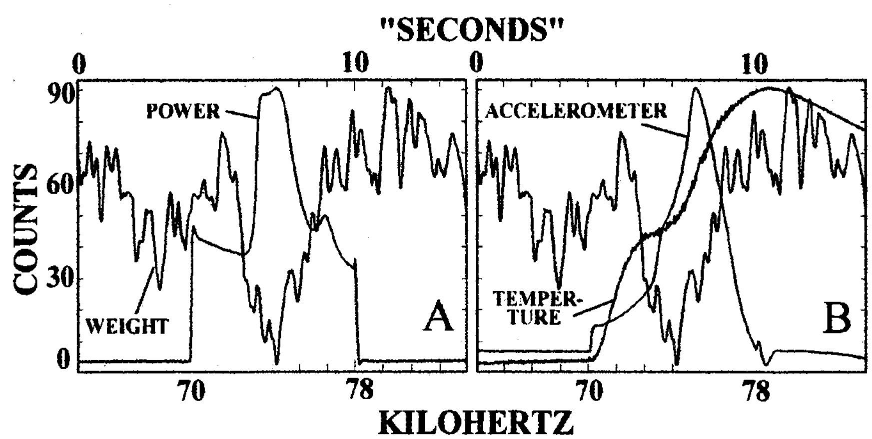

Figure 4: The weight fluctuation in the device shown in Figures 1 and 2 was swept with a sinusoidal signal. The weight is recorded in ADC counts, 66 counts scaling to 0.1 gram. The power trace shown in panel A peaks at 105 Watts. The corresponding thermistor (temperature) and accelerometer traces shown in panel B were not absolutely calibrated.

during power application presented in Figure 5 (taken with an Indigo Alpha Microbolometer camera). Prompt heating of the thermistor, evidently, is produced by vibration driven by the activated PZT stack. And the inflection in the thermistor trace shows that this vibration at the thermistor drops dramatically just before and during the onset of the power and accelerometer resonances.

This device and several others like it were actually designed to behave in this way, though they are so cranky that the preload on the PZT stack and the operating temperature must be "just so" to get them to work as intended. Indeed, the device used to obtain the data displayed showed such crankiness. When optimal operating conditions were not present, the inflection in the thermistor trace was markedly diminished. So thermistor trace inflection was used as a selection criterion for the inclusion of cycle data in the averaged result. (Roughly one cycle in four was rejected using the thermistor trace inflection criterion. The cycle rejection rate improved [decreased] with knowledge of the operation of the system during the course of data acquisition.)

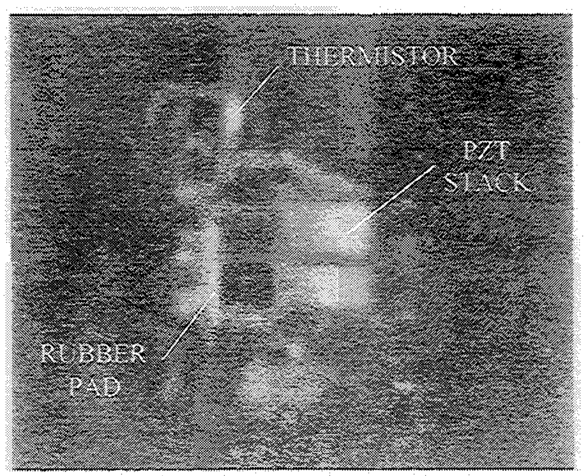

Figure 5: A far infrared image of the device during a power cycle. As expected, the bulk of the energy is delivered to the end of the PZT stack near the aluminum cap. Note too the prompt heating of the thermistor and rubber pads. The temperature rise in the stack during a power cycle is about 5 degrees Celsius.

One may ask: Is the weight fluctuation correlated with the power, thermistor, and accelerometer events is real, or just a statistical fluke? Inasmuch as the number of cycles averaged is about 250, and taking into consideration the weight trace away from the fluctuation, it seems quite plain that the correlated weight fluctuation is *most unlikely* to be a mere statistical fluke. More elaborate statistical analyses of the data are possible. For example, a formal error can be obtained by selective suppression of parts of the data and computing the mean and standard deviation of the spread of the resulting weight fluctuations. This, however, doesn't really shed more light on the significance of the result contained in Figure 4. Given that a weight fluctuation of the sort expected is seen in Figure 4, the question then is: Is the observed weight fluctuation caused by a real Machian effect? Or is it the consequence of the operation of some spurious signal source? Keeping in mind that, "extraordinary claims require extraordinary evidence," we turn now to the tests we have conducted to see if the signal in Figure 4 can be claimed to be real.

SPURIOUS SIGNALS AND CHECK PROTOCOLS

If we assume that the weight fluctuation signal in Figure 4 is *not* due to the predicted Machian effect, then, evidently, it must be a consequence of either the electromagnetic signals present during activation of the device or the mechanical vibration induced by those signals, for no other possibilities worth considering exist. Of these two classes of potential spurious signals, those due to electromagnetic effects are much easier to deal with. All one has to do is recreate the electromagnetic signals without driving the electromechanical response in the PZT stack to test for their effects. This is easily done by shorting out the PZT stack while applying the same voltage signal to another, similar device wired into the circuit far from the weigh system. This way all of the currents and voltages in the device can be emulated, but the electromechanical response that purportedly produces the effect is not excited. Figure 6 displays the results of

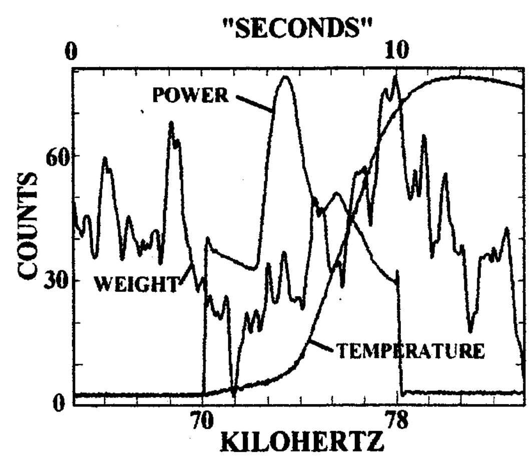

Figure 6: The averages of the current and voltage emulation weight traces. Note the absence of any weight fluctuation correlated with the peak of the power resonance.

this test. Very obviously, no weight fluctuation of the sort seen in Figure 4 is present, so the effect seen cannot be attributed to this source. A small systematic effect is seen in Figure 6 however. It is caused by the heating of the power leads to the device. (This heating effect is not seen in Figure 4 because data for two lead configurations were averaged together to cancel it out.)

The fact that the current and voltage emulation test does not *exactly* replicate all of the conditions present in the actual data runs makes possible the elimination of another potential source of spurious signals. When the device is actually run, one of the power leads is "hot" while the other is at ground potential. In emulation runs either both leads are hot, or both are not. A moment's reflection should convince one that the "both not" configuration more nearly approximates actual running conditions. Nonetheless, emulations were done in both configurations, and averaged together in Figure 6 because there was no significant difference in the results for the two configurations. In the "hot" configuration, however, since the entire device is (periodically) driven to high voltage, dielectrics in proximity to the device (the vacuum case in particular) will be polarized by the electric field. Since the field may be expected to have large gradients, these polarization charges might interact with the field, and thus the device. Roughly half of the data averaged in Figure 6 being for the "hot" configuration, it shows that no such effects are present.

Other tests of electromagnetic effects were carried out; notably, static magnetic fields of a few Gauss were applied to the system during its operation. No detectable effect was found in any of these tests that would lead one to suspect the effect seen in Figure 6 to be spurious. Mechanical vibration, the other leading candidate for spurious effects, was dealt with chiefly by aggressive vibration suppression and careful monitoring of vibration in the U-80 transducer. In addition, a test involving a unique signature of the negative mass effect was carried out. Note that the negative mass term in Equation (3) above depends on the square of the time derivative of the matter density. Thus, it also depends on the square of the energy density, and ultimately the square of the applied power (and their time derivatives). Normal effects driven by mechanical vibrations, however, may be expected to scale linearly with the applied power.

Although simple in principle, this test is difficult to carry out in practice for several reasons, chiefly secular evolutionary changes in the system during the extensive data runs needed to get even plausible results. Nevertheless, we present results of such a test in Figure 7. They cannot be claimed to be compelling, especially given the noise in the low power weight trace. Moreover, the differences in the power curves for the two power levels casts further doubt on simple comparisons of the two responses. But notwithstanding theses caveats, the predicted power scaling appears to be present.

So far we have considered voltage and current emulation, the induction of electric dipoles in surrounding media, static magnetic fields, the vibration measurements of the mounting stage accelerometer, and the power scaling behavior of the system. And all results are consistent with a real Machian mass fluctuation as the cause of the signals in Figures 4 and 7. It would seem that but a few potential sources of spurious results remain to be considered. Perhaps the most important of these are corona and sonic wind. Both of these depend strongly on the density of the air in which the device is run. So they may be explored by noting any change in the behavior of the system as the pressure in the vacuum vessel is changed. To insure that these effects were not responsible for the signals seen, the device was run at atmospheric pressure, 150 microns, and the normal operating pressure of roughly 15 microns. No noticeable change in behavior with pressure was observed, allowing us to set aside these possible sources of signals. (Nonetheless, the device was operated at the pump limit of about 15 microns except during these tests.)

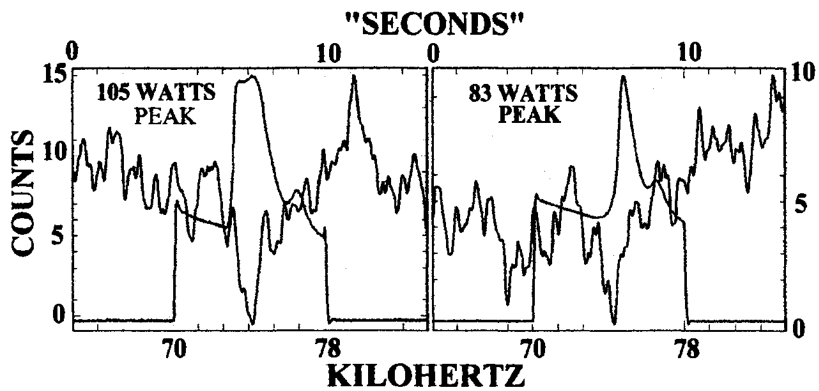

Figure 7: The weight fluctuations recorded for two different power levels. Note that whereas the ratio of the powers is 1.27, the ratio of the weight fluctuations is about 1.6, suggesting that the weight fluctuation scales with the square of the applied power.

In light of the results of the tests we report here, perhaps the most important test remaining is the replication of the main result using a completely different weigh system – in particular, a system like the cantilevered beam mentioned above. Time has not permitted us to complete such a test by the time of this writing. But we hope to have one done shortly.

CONCLUSION:

As noted above, the Saganism that extraordinary claims require extraordinary evidence is certainly true. Extraordinarity, however, like beauty, is in some measure in the eye of the beholder. So whether the evidence we present here rises to that level is a matter of individual judgment. Our judgment is that the evidence suggests that a real effect is present; although, being quite cranky, it is far more difficult to produce and manipulate than we would like. Partly, perhaps, these difficulties can be attributed to the very modest effort involved. Greater effort, we think, is warranted.

But where, beyond further confirmation and exploration of the effects reported here, does one go from here? Well, from the point of view of rapid spacetime transport two issues seem to be the most important. First, can the effects reported here be scaled to useful levels? A mass fluctuation of a tenth of a gram or so is only of laboratory interest. It is worth noting that the negative mass term effect, everything else held constant, scales with the square of the frequency and with the square of the power. So, in principle, very large mass fluctuation effects should be producible with only relatively modest power levels. We hasten to add that there are subtleties to the production of this effect that are not yet fully explored. For example, generation of the effect seems to depend quite critically on the production of higher harmonics in the PZT stacks, for sinking a lot of power into a stack at a mechanical resonance of the stack is not, itself, sufficient to yield an effect. The details of the processes that lead to large mass fluctuations need to be studied and *understood* in some detail before serious engineering is undertaken.

Second, from the point of view of propellantless propulsion, the creation of impulse engines requires that objects with induced mass fluctuations be acted upon by another periodic force to extract a stationary force. In the torsion pendulum experiments that preceded those sketched here, two of us (JFW and TLM) were only able to produce minuscule forces many orders of magnitude smaller than those expected on the basis of naïve calculations. Likely this can in part be attributed to subtleties involving the yet to be explored details of the production of mass fluctuations in real non-linear systems. These details will have to be sorted out before the dream of propellantless propulsion can be fully realized.

In this regard we note that it may be worth exploring systems other than simple stacks of PZT crystals driven with complex voltage waveforms (like those already investigated by TLM and JFW). For instance, one might expect to see impulse engine effects in the system described by Corum, *et al.* where a sinusoidal voltage is applied to a circuit with an inductor and capacitor in series.[3] The inductor is arranged so that the periodic magnetic field it generates permeates the dielectric between the plates of the capacitor, orthogonal to the electric field therein. Taken as a strictly electromagnetic system, the conservation principles mentioned at the outset of this paper require that any forces produced in the dielectric be balanced by equal and opposite forces elsewhere in the circuit. So there is no reason to expect to see strictly electromagnetic propulsive forces in this type of system.

But note that if Machian mass fluctuations actually occur, then the acceleration of the charge carriers that comprise the displacement current in the dielectric in the capacitor, driven by the periodic electric field, will induce a mass fluctuation at the power frequency of the voltage frequency – that is, at twice the frequency of the applied voltage signal. Now consider the action of the magnetic field. The motion of the displacement current charge carriers will interact with the period magnetic field to yield a force on the charge carriers via the magnetic part of the Lorentz force: $(q/c)(\boldsymbol{v} \times \boldsymbol{B})$. Since the velocity of the charge carriers, $\boldsymbol{v}$, and the magnetic field, $\boldsymbol{B}$, are both periodic with a frequency equal to the applied voltage frequency, their cross product will yield a force with twice this frequency -- that is, the frequency of the mass fluctuation putatively being driven by the action of the electric field in the dielectric. Should the relative phase of the mass fluctuation and the magnetic part of the Lorentz force be auspicious, a stationary force should result.

Such a force, if present, is a result of the mass fluctuation that arises from the inertial coupling of the constituents of the dielectric to the rest of the universe. It is not due to a local violation of the conservation of momentum in a purely electrodynamical system. It is worth remarking that a stationary force in a system of this sort may be expected even if the "substance" between the plates of the capacitor is the vacuum. If the charged particle pair production in the vacuum of quantum lore actually takes place, the pairs should experience the same effects as material dielectric media. So exploration of this sort of arrangement of circuit elements has scientific value (as a test of the "polarizable vacuum" conjecture), as well as potential technological implications.

Finally, we note that the nearly 0.1 gm mass shift that seems to have taken place in the PZT stack approaches a percent of the total mass of the PZT material (about 40 gm), and this with an applied power on the order of 100 Watts. If this effect is real, and should no physical mechanism operate that enjoins true negative total mass states, then it seems that we may be able to actually generate, however fleetingly, truly exotic matter. Should this prove possible, the most extreme sorts of rapid spacetime transport may be feasible. Experiments designed to probe these possibilities, however, should be undertaken with some care.

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The work now in progress at CSUF has profited significantly from important contributions of others. They have contributed in several veins. Kirk Goodall helped with the construction of parts of the apparatus, participated in many discussions about the experiment, and did some of the testing of various systems. Probing questions and comments from John Cramer, Michael Dornheim, Edward Harris, and Graham O'Neil, among others, have made us think carefully about several important aspects of Machian mass fluctuations and their application to rapid spacetime transport. And the careful critiques of colleagues at CSUF, especially Ronald Crowley and Stephen Goode have been essential. Indeed, those critiques are largely responsible for the appreciation of the significance of the negative mass term in Equations (1) and (2) that underlies the work reported here.

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Global Monopoles and the Bondi-Forward Mechanism

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GLOBAL MONOPOLES AND THE BONDI–FORWARD MECHANISM

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Abstract. Based on work by Bondi, Forward considered the possibility of using putative negative masses for a propellantless propulsion mechanism. Recent advances in the study of black holes in the presence of fields may provide an explicit mechanism to mimick the effects of negative mass without the need to invoke exotic quantum effects, or to postulate the existence of matter with negative mass in the classical domain. We evaluate the feasibility of using such objects in a Bondi–Forward type propulsion mechanism.

1. Introduction

Bondi[1] was the first to consider the effects of putative negative masses within classical general relativity. As pointed out by Forward[2], negative mass could be used to create a propellantless propulsion mechanism.

The underlying principle can most easily be understood in Newtonian mechanics. Consider a point particle 1 with gravitational mass $m > 0$ and a particle 2 with mass $-m$, both moving along the x–axis of a Cartesian coordinate system. Let $\bar{e}_x$ be the unit vector pointing in the positive x–direction, and suppose that initially $x_2 < x_1$, where x_1 and x_2 are the coordinates of particle 1 and particle 2, respectively. Particle 2 exerts a force on particle 1 equal to

$$\bar{F}_1 = -\frac{G(-m)m}{(x_1 - x_2)^2}\bar{e}_x = \frac{Gm^2}{(x_1 - x_2)^2}\bar{e}_x, \tag{1}$$

while particle 1 exerts a force on particle 2 given by

$$\bar{F}_2 = \frac{Gm(-m)}{(x_1 - x_2)^2}\bar{e}_x = -\frac{Gm^2}{(x_1 - x_2)^2}\bar{e}_x. \tag{2}$$

Note that the forces are equal in magnitude but have opposite direction, in accordance with Newton's third law. To get the accelerations, we now have to divide the forces by the respective *inertial* masses. We will assume these to be equal to the gravitational masses, including the sign. To fully understand why this is a reasonable assumption, one would have to take recourse to general relativity[1]; we will also come back to this issue in Section 3. Dividing $\bar{F}_1$ by m and $\bar{F}_2$ by $-m$, we find the accelerations for particle 1 and particle 2 to be

$$\bar{a}_1 = \bar{a}_2 = \frac{Gm}{(x_1 - x_2)^2}\bar{e}_x. \tag{3}$$

This means that both particles will undergo an acceleration *in the same direction*, and this acceleration will persist until the relativistic regime is reached. (Note that in this special case the magnitudes of the accelerations are also equal to each other; this is just because we chose the absolute values of the masses to be the same.) Again taking into account the signs of the masses, it will be clear that both the (Newtonian) total momentum and total kinetic energy are conserved. (In fact, in this case both are identically zero for all times.)

Negative masses have never been observed in Nature, although it is generally assumed that quantum field theory effects can give rise to negative energy densities (a very readable introduction can be found in Visser's book[3]). In this paper, we will describe a possible mechanism to *mimick* the effects of negative mass, starting from purely classical physics. Our tools will be general relativity, together with the classical theory of the weak and strong nuclear interactions.

As it is well–known, black holes can carry an electric charge, and when a charged particle is moving in such a spacetime, it will feel the effect of both the charge Q of the hole and its mass M. Since energy is stored in the electric field generated by the charge Q, it will contribute to the curvature of spacetime in the vicinity of the hole. Because of the fact that in general relativity, the gravitational force is a result of the curvature of spacetime, this contribution will make it seem as if the hole has a mass different from M. Consequently, even the motion of an *uncharged* particle in such a spacetime will be different from what it would have been if the hole had only carried a mass M, and no charge. In particular, the particle will appear to be moving in the gravitational field of a mass that is *smaller* than M.

It is a generic feature of general relativity that objects appear to have a mass that is smaller than their actual mass content (see e.g. Wald[4]). Consider the example of a spherical, non–rotating star. According to Birkhoff's theorem, the geometry outside the star is that of Schwarzschild spacetime, with some characteristic mass $\tilde{M}$. This is the mass outside observers will *perceive* the star to have, for example by releasing test particles and observing their motion. As it turns out, $\tilde{M}$ will always be slightly smaller than the 'proper' mass content M of the star (i.e., the mass that went into the star when it formed). If we define $\Delta M = M - \tilde{M}$, then $E_B = \Delta M\, c^2$ may be interpreted as the gravitational binding energy.

It needs to be stressed that the latter is merely a heuristic statement, since gravitational binding energy has no general definition. Even so, one could ask the following question: Can a self–gravitating object be so strongly bound that its apparent mass is negative (i.e., can the contribution to the mass due to binding energy be larger than the proper mass content)? Preliminary investigations seem to point towards a positive answer. The purpose of this paper is to describe under what circumstances this could come about, and to evaluate its relevance for the Bondi–Forward (BF) propulsion mechanism.

The paper is structured as follows. In the next Section, we will introduce solutions to Einstein gravity in the presence of additional, non–gravitational fields, which for all practical purposes have a negative gravitational mass, even though the energy stored in the fields, as well as any proper mass that may be present, are positive. In Section 3, we first of all evaluate to what extent the objects described may be considered realistic, or physically acceptable, and we consider the problems that may be expected when incorporating them in BF propulsion. Conclusions are presented in Section 4. Although we will assume that the reader has some knowledge of basic relativistic physics, we will review the theory of the Higgs field and its coupling to gravity in the Appendix, as it will be the basis for the more promising class of objects discussed in Section 3.

Throughout this note we will use units such that $G = c = \hbar = 1$, unless stated otherwise. The signature of spacetime metrics is chosen to be $(-,+,+,+)$.

2. Black holes with negative mass

The fact that in the presence of fields, black holes can appear to have negative mass has been known for quite some time; it is apparent in the solutions discovered by Barriola and Vilenkin[5]. Recently, two classes of black holes with negative effective mass were studied in detail. In what follows, we will talk about proper mass and proper charge; for definiteness, let us first define these rigorously. The spacetimes we will consider all have a metric of the form

$$ds^2 = -\sigma^2 N dt^2 + N^{-1} dr^2 + r^2(d\theta^2 + \sin^2\theta\, d\phi^2), \quad (4)$$

where σ and N are functions of r. Define $u(r) = r^2 N(r)$ and expand this function near $r = 0$:

$$u = Q^2 - 2Mr + \dots. \quad (5)$$

By definition, Q is the proper charge and M the proper mass. This definition is motivated by the fact that in the case of a charged black hole, Q and M are indeed the amounts of charge and mass that end up in the hole as it is formed. These should be distinguished from the *effective* charge and mass, which are the values measured by an outside observer, e.g. using test particles.

So far we have only talked about black holes carrying the electric charge associated to electromagnetism. However, holes can also have proper charges associated to the weak and strong nuclear forces. Just like electromagnetism, these interactions are described by *gauge theories*, which are characterized by some internal group of invariances, or *symmetries*. (In the case of electromagnetism, this is the invariance of the electric and magnetic fields when adding to the vector potential the gradient of an arbitrary smooth function.) The symmetry group inherent in electromagnetism is called $U(1)$, and those of the weak and strong interactions are $SU(2)$ and $SU(3)$, respectively. The weak interaction is somewhat special, in that its symmetry is broken in Nature, presumably by interaction with the yet to be discovered Higgs field. For an elementary introduction into the physics involved, we refer the reader to the textbook by Aitchison and Hey[6].

Zotov[7] studied the appearance of black holes with negative effective mass in the context of *unbroken* $SU(2)$ gauge theory, called *Yang–Mills theory*. Although this model is not realized in Nature, it can be considered as a useful 'toy model' for the full $SU(3)$ theory describing the strong interaction. It is generally believed that the qualitative features of solutions of Yang–Mills theory coupled to gravity will usually carry over to $SU(3)$. Zotov's black holes have a proper mass, and also a proper charge. The latter is not the familiar charge of electromagnetism, but its $SU(2)$ equivalent. Numerical results suggest that Yang–Mills theory admits black hole like solutions with negative effective mass but positive proper mass. However, the solutions studied by Zotov do not have an event horizon; their singularities are naked. Although a proof is lacking, it is generally assumed that this cannot happen in Nature (this is the famous *Cosmic Censorship Conjecture*[8]), so we will not discuss these solutions any further.

Instead, we turn to the slightly earlier work of Nucamendi and Sudarsky[9]. They studied black hole solutions with an event horizon, arising from a model with three scalar fields having a broken *global* $O(3)$ symmetry. Here 'global' merely means that, unlike gauge symmetries, the transformations under which the theory is invariant are not allowed to depend on the position in spacetime. The broken $O(3)$ theory should be a good model for the Higgs interaction. It is assumed that there exists more than one Higgs. The way they interact among themselves will involve a global symmetry, which needs to be broken itself in order to break the $SU(2)$ symmetry of the weak interaction. The breaking occurs when the Higgs particles form a *condensate*, meaning that the Higgs fields acquire a non–zero vacuum expectation value.

A peculiar feature of the solutions presented by Nucamendi and Sudarsky is that they carry neither proper mass nor proper charge. Instead, they are 'topological defects', usually called *global monopoles*. A useful picture is that of a field which has been tied into a knot.

The energy stored in such a 'knotted' field can give rise to a spacetime geometry which is similar to that of a black hole with an event horizon. (Note that the term 'topological defect' refers to the gauge field itself, *not* the topology of the spacetime it gives rise to.) Henceforth, we will refer to the particular solutions found by Nucamendi and Sudarsky as *NS monopoles*.

In general, the equations describing the interaction between the fields and gravity in the model of Nucamendi and Sudarsky are too complex to solve analytically. As a consequence, the spacetime metrics for black hole like solutions can usually not be written in closed form. However, at large distances, NS monopoles have a metric that looks like

$$ds^2 \simeq -\left(1 - \frac{2\tilde{M}}{r}\right) dt^2 + \left(1 - \frac{2\tilde{M}}{r}\right)^{-1} dr^2 + (1-\alpha)\, r^2 (d\theta^2 + \sin^2\theta\, d\phi^2), \tag{6}$$

where $\alpha = 8\pi\eta^2$, with η the magnitude of the Higgs field condensate. The equations of motion for uncharged test particles with positive mass moving in the vicinity of the monopole are given by the geodesic equation. A particle that is initially at rest at sufficiently large distances will be subject to a radial proper acceleration

$$a_r \simeq \frac{-\tilde{M}}{r^2 - 2\tilde{M}r}. \tag{7}$$

As numerical results show, it is possible to have solutions with $\tilde{M} < 0$, so that $a_r > 0$: The central object is repelling the particle. For all practical purposes, the global monopole behaves as an object with negative mass.

It is worth pointing out that although the monopole behaves as if it carries negative mass/energy, all of the energy conditions of general relativity are satisfied because of the way the fields couple to gravity[10]. Therefore, no observer will ever measure negative energy density in this spacetime; the monopole indeed only *mimicks* the effect.

Note that the metric (6) is not asymptotically flat: In the limit $r \to \infty$, one does not retrieve the usual uncurved (or Minkowski) spacetime. Rather, the geometry is 'asymptotically flat up to a deficit angle'. This means that if we were to measure the surface area of a sphere with very large radius R centered on the black hole, we would not find the usual value of $4\pi R^2$, but rather $4\pi(1-\alpha)R^2$. We will come back to this important fact in the next section.

3. Global monopoles and the BF mechanism

Although the NS monopoles satisfy most of the criteria to be physically acceptable solutions of the broken $O(3)$ theory coupled to gravity, it is not known how they could be created in Nature. The relevant literature is very recent, and it deals only with static solutions, so that at this time it would be inappropriate to speculate on how global monopoles with negative effective mass might come about. This makes it impossible to assess how much energy is needed to generate these objects. As we mentioned, the proper mass is zero; all energy is stored in the fields. In general relativity there is no generic scheme to compute the energy stored in a particular fields configuration, especially for solutions that are not asymptotically flat.

The failure of the metric (6) to be asymptotically flat is a possibly problematic feature from a physical point of view. The deficit angle will create tidal stresses. As we mentioned in the previous section, the magnitude of α is determined by the magnitude of the Higgs field condensate. The magnitude of the stresses on a compact object of fixed size will depend on distance; even though the metric is not asymptotically flat globally, it still approaches flatness locally. A good analogy is to consider the surface of a cone. The spheres of radius R we talked about in the previous section are now circles on the cone in a plane perpendicular to the cone's axis. R should be interpreted as the distance of a circle from the apex of the cone, so that their circumference is $2\pi(1-\beta)R$, with $2\pi\beta$ some deficit angle. But now consider a disk of radius ρ stuck on the surface of the cone. If the disk is close to the apex, its surface area will be smaller than $\pi\rho^2$. However, as one slides the disk away from the apex while keeping ρ fixed, the curvature of the cone's surface becomes less noticeable and the area of the disk will tend to $\pi\rho^2$ asymptotically. Similarly, in the spacetime (6), a spherical object with radius ρ will have a volume smaller than $4\pi\rho^3/3$ when close to the central singularity, but as it is moved away from it while keeping ρ fixed, the volume *will* tend to that value.

The magnitude of the Higgs condensate is expected to be $\eta \simeq 250\ \mathrm{MeV/m^3}$; in units where $G = c = \hbar = 1$, this becomes $\eta \simeq 5 \times 10^{-126}$, so that the deficit angle $4\pi\alpha = 32\pi^2\eta^2$ will be of no consequence in the regime where the approximation (6) is valid.

NS monopoles have two characteristic length scales associated to them: The radius of the event horizon r_h, and the monopole's 'core radius' r_c. The latter is completely fixed by the mass the Higgs bosons themselves acquire due to symmetry breaking. Different NS monopole solutions are characterized by different values of r_h. Negative effective masses occur when $r_h \ll r_c$, so that for these solutions the metric (6) is a good approximation for $r \gg r_c$. In units where $G = c = \hbar = 1$, one has $r_c = 1/(\sqrt{2}m_H)$. Although the Higgs mass is as yet unknown, it is generally assumed to be approximately $m_H \simeq 200$ GeV. In SI units, this gives $r_c \sim 10^{-35}$ m. For all practical purposes, the monopole can be considered as a point particle.

The smallness of the core radius raises an important question. So far, we have been discussing purely classical field theory, both on the gravitational and on the Higgs side. However, r_c is comparable to the Planck length. This means that realistic NS monopoles are not only essentially quantum mechanical objects; quantum gravity effects can be expected to influence their structure in a major way. As yet, no quantum gravity theory has been verified either experimentally or observationally, so that it is impossible to say what these effects will do to the monopole. However, although the Higgs mass is a parameter in the Standard Model of elementary particle physics, it is not generally considered to be a fixed constant of Nature. This is because it is not only determined by the coupling strength of the Higgs self–interaction, but also by the magnitude of the Higgs condensate. The latter is expected to be a consequence of the particular conditions that existed shortly after the Big Bang[11]. It is not unimaginable that its value could be changed locally, although any statement as to how this could be done would again be pure speculation. For now, I will confine myself to saying that it is justifiable to continue the discussion on the basis of the qualitative results from the classical theory.

Without going through the full numerical computation for the spacetime geometry, from looking at the evolution equations in the paper by Nucamendi and Sudarsky[9] one can immediately tell that if $\alpha \simeq 0$, the effective mass will also be exceedingly small. Nevertheless, one can think of schemes to use NS monopoles for BF propulsion. For instance, consider a very large number of them contained in a spherical shell of positive mass. Using Newtonian arguments again, the spherical shell will not influence the effectively negative mass inside; as it is well–known, such a shell acts like the gravitational equivalent of a Faraday cage. On the other hand, negative mass particles will repel both each other and the surrounding shell. One can therefore conceive of a thin, spherical, positive mass shell filled homogeneously with negative mass. If the amount of negative mass inside is much larger in absolute value than the mass of the shell, the net gravitational field outside will be that of a negative point mass. Still using Newtonian arguments, for an amount of negative mass in the order of, say, a large asteroid mass ($M \sim -10^{20}$ kg), the outward pressure on the spherical shell will be comparable to the inward pressure felt by the matter in a positive mass asteroid (this is of course assuming the dimensions are comparable). Close to the shell, the repulsive gravitational force will be the same in magnitude as the (attractive) force caused by an asteroid with the same (positive) mass and dimensions. This will then be the force acting on a positive 'payload' mass placed close to the shell.

A possible implementation of the BF mechanism would consist of a container of NS monopoles together with a positive payload mass, which would act as the positive mass particle in the system. Now a new question arises: Although we know that the container will repell the payload, can we be sure that the payload will attract the container? Phrased differently, is the inertial mass of NS monopoles equal to the negative effective mass? Recall from the Introduction that it was precisely the fact that we divided the force on the particle with negative gravitational mass by $-m$ that led to an acceleration in the same direction as that of the positive mass particle. The inherent assumption was the equality of graviational and inertial mass. So far, we have tacitly assumed that this equality holds for NS monopoles. Are we justified in doing so?

When computing the inertial mass of e.g. a proton, the binding energy of its quarks due to the strong nuclear interaction needs to be taken into account to arrive at the correct result. Similarly, if the negative effective mass of NS monopoles is to be understood as a consequence of gravitational binding energy (cf. the example of the spherical non–rotating star), then one expects a positive answer.

Since gravitational binding energy is but a heuristic concept, a more fruitful way of looking at the problem is to consider the metric caused by an isolated payload mass. Supposing the payload mass is spherically symmetric, the metric of the geometry outside will be Schwarzschild. If the negative mass container is sufficiently far away, it can be considered as a point particle. Alternatively, one could look at the motion of just a single NS monopole, which for all practical purposes should behave as a test particle in the technical sense: A point particle with negligible mass. It is reasonable to assume that a single monopole will move on a geodesic, and that this will also be approximately true for a container of macroscopic extent. Since the geodesic equation is insensitive to the mass of the point particle of which it describes the motion, in that case a monopole, and a negative mass container, would certainly be attracted by the payload.

The geodesic equation can be derived from Einstein's equations by considering the motion of an extended body in curved spacetime and taking the limit where its spatial extent goes to zero. The derivation is subtle, as was made clear most recently by the work of Mino, Sasaki and Tanaka[12], and Quinn and Wald[13]. In the case of a small and light NS monopole superposed on a curved background, the analysis will be extremely complicated, partly because of the internal structure of an monopole, and especially because of the fact that the spacetime geometry is not asymptotically flat. A direct proof that NS monopoles will move on geodesics can be expected to be very difficult.

Because of its importance for the BF mechanism, the issue of inertia calls for further investigation. To evaluate the inertial mass rigorously, one needs a detailed study of the behavior of NS monopoles in a dynamical situation. One possibility would be to construct a binary solution of two NS monopoles connected by a 'strut'. Such constructions have been carried out for binary black hole solutions (a recent reference is Letelier and Oliveira[14]). If NS monopoles have negative inertial mass as well as negative effective mass, what we would expect for a monopole pair is that the connecting strut would tend to be stretched. Alternatively, one could consider perturbations of the NS monopole metric with non-zero momentum and study the recoil effects, as has been done by Andrade and Price[15] for ordinary black holes.

Assuming that the system composed of the negative mass container and the payload mass can not go superluminal, it is easy to guess what will happen as it approaches relativistic speeds. The neutral positive matter can only radiate gravitationally. Since the Higgs interaction is much stronger than the gravitational one, the NS monopoles inside the shell will start radiating 'Higgs field waves' before the positive matter loses energy through gravitational wave emission. The Higgs radiation will carry off positive energy: The positive energy stored in the fields composing the monopoles. The strength of those fields then diminishes, and the effective negative mass becomes less negative *even though positive energy is being radiated away.* We reiterate that although the monopoles generate a repulsive gravitational force indistinguishable from that of negative mass, the true energy density is positive everywhere.

4. Summary and conclusions

We have described a possible implementation of the Bondi–Forward propulsion mechanism on the basis of global monopoles arising in a spontaneously broken $O(3)$ Higgs model coupled to gravity. Clearly, there are several open problems, each of them crucial to the relevance of NS monopoles in the context of the BF scheme.

The typical length scale of a monopole with negative effective mass is the core radius, which is determined by the Higgs mass and turns out to be of the order of the Planck scale. In that case, the classical description is inappropriate, and a description in terms of quantum gravity is called for. Since no quantum gravity theory has ever been tested, it is impossible to say at this point how this will effect the properties of the monopole. However, the Higgs mass depends both on the coupling strength of the Higgs self-interaction and the magnitude of the condensate. Both are parameters in the Higgs potential (see the Appendix), and standard lore[11] has it that this potential is dynamically generated by whatever physics goes on at very high energies. Consequently, it is possible that these parameters can be changed in a physical process, but the theoretical framework to even conceive of a mechanism to bring this about is not yet in place.

So far, the study of solutions to the theory of the Higgs coupled to gravity has been confined to static ones. As a result, no physical mechanism is known in which NS monopoles might be created. Since these objects do not have a proper mass or charge, this makes it hard to even estimate how much energy would be involved.

The most pressing problem is the question whether NS monopoles with negative effective mass also have negative inertial mass. One would expect a positive answer, but this should not be taken for granted. We have indicated a number of ways in which it could be tested computationally. It seems unrealistic to hope for a direct proof that the motion of NS monopoles is approximately geodesic, but we have proposed other schemes which have already been worked out for less exotic objects.

It will be clear that a full evaluation of the possibility of using NS monopoles to implement the BF mechanism would require a protracted effort on the theory side. Even then, it seems unlikely that a definite statement could be made on the basis of what we currently know about high energy physics. But at least there is some hope; even though negative mass presumably does not exist in its 'pure' form, Nature may have given us a loophole.

Appendix

It is generally assumed that the breaking of the $SU(2)$ gauge symmetry of the electroweak interaction is a consequence of the breaking of a *global* symmetry associated with the dynamics of the Higgs fields. Nucamendi and Sudarsky considered a theory with three Higgs fields ϕ^a, $a = 1, 2, 3$, interacting with each other according to a potential

$$V(\phi^a) = V(\phi^1, \phi^2, \phi^3) = \frac{\lambda}{4}(\phi^2 - \eta^2)^2, \qquad (8)$$

where ϕ^2 is shorthand for $\sum_{a=1}^{3} \phi^a \phi^a$. Note that if one would set e.g. ϕ^3 to zero and consider only ϕ^1 and ϕ^2, a diagram of the potential versus ϕ^1, ϕ^2 would resemble a Mexican hat. Indeed, $V(\phi^a)$ then has a local maximum at the origin of the (ϕ^1, ϕ^2)–plane given by $V(0,0,0) = (\lambda/4)\,\eta^4$ (the top of the 'hat'). As one moves away from the origin, the potential decreases until the valley defined by $\phi^2 = \eta^2$ is reached, where $V = 0$ (the rim of the hat). Moving still further away from the origin, V increases without bound.

What cosmologists generally expect to have happened during the early phases of the Universe can be very roughly described as follows. Shortly after the Big Bang, when the temperature of the Universe was still very high, η was equal to zero, so that the potential had a unique minimum at the origin and increased without bound as one moved away from the origin. The equilibrium value for the classical fields ϕ^a was then $\phi^a = 0$ for $a = 1, 2, 3$, since the potential is then at its minimum, $V = 0$. As the Universe cooled down, η increased and the potential formed a 'bump' near the origin, leading to the Mexican hat shape. The values $\phi^a = 0$ now corresponded to an unstable equilibrium point: The top of the 'hat'. Consequently, the fields ϕ^a acquired non–zero values throughout spacetime, namely values that minimized the new potential. But note that for $\eta \neq 0$, (8) does not have a unique minimum; all values of ϕ^a for which $\phi^2 = \eta^2$ are a minimum of the potential. Which minimum the fields ended up in was determined by the small perturbations causing the field configuration to be pushed away from the unstable equilibrium point, and may be considered arbitrary for all practical purposes. The situation is comparable to that of a pencil balanced on its tip: The pencil could fall in any direction. This process is called *spontaneous symmetry breaking*. The result is that the classical values of the Higgs fields are no longer zero; in the jargon one says that the particles associated to the fields have formed a *condensate* ϕ^a such that $\phi^2 = \eta^2$. η is the magnitude of the condensate; presumably it is determined by the specific conditions existing in the early Universe, together with the dynamics of the as yet unknown high–energy physics driving the symmetry breaking. The terminology stems from a very analogous process in condensed matter physics, the Meissner effect, which is responsible for superfluidity and superconductivity.

In a curved spacetime, the field equations governing the classical dynamics of the Higgs fields are given by

$$\nabla_\mu \nabla^\mu \phi^a = \frac{\partial V}{\partial \phi^a}, \tag{9}$$

where the ∇_μ ($\mu = 0, \ldots, 3$) are the covariant derivatives associated to the metric; in flat spacetime these would simply be the partial derivatives with respect to the coordinates. (Raising and lowering of indices is done using the metric and its inverse, and as always summation over repeated indices is implied.) Using the expression for the potential (8), the field equations (9) can be written in more detail as

$$\nabla_\mu \nabla^\mu \phi^a + \lambda \eta^2 \phi^a - \lambda \phi^2 \phi^a = 0. \tag{10}$$

As usual, the prefactor of the term that is linear in the fields and carries no derivatives gives us the square of the mass[7], so that the Higgs mass is equal to $m_H = (\lambda \eta^2)^{\frac{1}{2}}$. Apart from that, there is a cubic interaction of the Higgs among themselves, with coupling strength λ.

The presence of the fields affects the geometry of spacetime through the Einstein equations,

$$R^{\mu\nu} - \frac{1}{2} g^{\mu\nu} R = 8\pi T^{\mu\nu}. \tag{11}$$

Here $R^{\mu\nu}$ is a tensor formed from the metric $g_{\mu\nu}$ and its first and second derivatives, $R = R^{\mu\nu} g_{\mu\nu}$, and $T^{\mu\nu}$ is the stress–energy tensor of the Higgs fields. One has

$$T^{\mu\nu} = \nabla^\mu \phi^b \nabla^\nu \phi^b - g^{\mu\nu} \left[\frac{1}{2} (\nabla^\kappa \phi^b)(\nabla_\kappa \phi^b) + V(\phi^a) \right], \tag{12}$$

where summation over the indices b is assumed. For derivations we refer to Aitchison and Hey[7] and Hawking and Ellis[10].

To solve the equations (9) and (11), Nucamendi and Sudarsky started with the ansatz

$$\phi^a = \eta f(r) \frac{x^a}{r} \tag{13}$$

for the fields, and

$$ds^2 = -\left(1 - \frac{2m(r)}{r}\right) e^{-2\delta(r)} dt^2 + \left(1 - \frac{2m(r)}{r}\right)^{-1} dr^2 + (1-\alpha)\, r^2 (d\theta^2 + \sin^2\theta\, d\phi^2) \tag{14}$$

for the spacetime metric. The x^a are spatial asymptotic Cartesian coordinates, obtained from (r, θ, ϕ) in the same way as Cartesian coordinates in Euclidean space. The functions $f(r)$, $m(r)$, and $\delta(r)$ are to be obtained from the field equations (9) and the Einstein equations (11), with suitable boundary conditions. We note in passing that (14) is indeed of the form (4).

The natural boundary condition for f as $r \to \infty$ is $f(r) \to 1$, since one wants the Higgs fields (13) to tend to a minimum of the potential, i.e., $\phi^2 \to \eta^2$. As was shown by Barriola and Vilenkin[5], the asymptotic behavior (6) then leads to a globally well–defined solution for both the fields and the metric (apart from a central singularity). However, in numerically solving (9) and (11), Nucamendi and Sudarsky found it more convenient to impose boundary conditions at the origin $r = 0$:

$$\begin{aligned} f(0) &= 0, \\ m(0) &= 0, \\ \frac{\partial m}{\partial r}(0) &= -\frac{\alpha}{2(1-\alpha)}. \end{aligned} \tag{15}$$

The fact that one needs $f \to 1$ as $r \to \infty$ then imposes a unique value for $\partial f / \partial r$ at $r = 0$, which can only be determined by a 'shooting method': Different values are tried out until a consistent solution for fields and metric is obtained. For more details, the reader is encouraged to read the original paper[9].

Using the conditions (15), it is easy to convince oneself that the proper mass and charge of an NS monopole as defined by the expansion (5) are indeed zero. The function $u(r)$ is

$$u = r^2 \left(1 - \frac{2m(r)}{r}\right) = -2m(r) r + r^2. \tag{16}$$

Near $r = 0$ there is no zeroth order term in r, so $Q = 0$, and since $m(0) = 0$ the first order term vanishes as well, which gives $M = 0$.

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Induction and Amplifications of Non-Newtonian Gravitational Fields

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Induction and Amplification of Non-Newtonian Gravitational Fields

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One obtains a Maxwell-like structure of gravitation by applying the weak-field approximation to the well accepted theory of general relativity or by extending Newton's laws to time-dependent systems. This splits gravity in two parts, namely a gravitoelectric and gravitomagnetic (or cogravitational) one. Both solutions differ usually only in the definition of the speed of propagation, the lorentz force law and the expression of the gravitomagnetic potential energy. However, only by extending Newton's laws we obtain a set of Maxwell-like equations which are perfectly isomorphic to electromagnetism. Applying this theory to explain the measured advance of the mercury perihelion we obtain exactly the same prediction as starting from general relativity theory. This is not possible using the weak-field approximation approach. Due to the obtained similar structure between gravitation and electromagnetism, one can express one field by the other one using a coupling constant depending on the mass to charge ratio of the field source. This leads to equations e.g. of how to obtain non-Newtonian gravitational fields by time-varying magnetic fields. Unfortunately the coupling constant is so small that using present day technology engineering applications for gravitation using electromagnetic fields are very difficult. Calculations of induced gravitational fields using state-of-the-art fusion plasmas reach only accelerator threshold values for laboratory testing. Possible amplification mechanisms are mentioned in the literature and need to be explored. We review work by Henry Wallace suggesting a very high gravitomagnetic susceptibility of nuclear half-spin material as well as coupling of charge and mass as shown by e.g. torque pendulum experiments. The possibility of using the principle of equivalence in the weak field approximation to induce non-Newtonian gravitational fields and the influence of electric charge on the free fall of bodies are also investigated, leading to some additional experimental recommendations.

1. Introduction

The control and modification of gravitational fields is a dream pursued by propulsion engineers and physicists around the world. NASA's Breakthrough Propulsion Physics Project is funding exploratory research in this area to stimulate possible breakthroughs in physics that could drastically lower costs for access to space[1]. Although not commonly known, Einstein's well accepted general relativity theory, which describes gravitation in our macroscopic world, allows induction phenomena of non-Newtonian gravitational fields similar to Faraday induction in electromagnetic fields by moving heavy masses at high velocities.

The basis for such phenomena are even dating back before general relativity theory when Oliver Heaviside[2] in 1893 investigated how energy is propagated in a gravitational field. Since energy propagation in electromagnetic fields is defined by the Poynting vector – a vector product between electric and magnetic fields – Heaviside proposed a gravitational analogue to the magnetic field. Moreover he postulated that this energy must also be propagating at the speed of light. Another approach to the magnetic part of gravity is to start from Newtonian gravity and add the necessary components to conserve momentum and energy[3]. This leads to the same magnetic component and a finite speed of propagation, the speed of light.

Heaviside's gravitomagnetic fields are hidden in Einstein's Tensor equations. Alternatively, general relativity theory can be written as linear perturbations of Minkowski spacetime. Forward[4] was the first to show that these perturbations can be rearranged to assemble a Maxwell-type structure which splits gravitation into a gravitoelectric (classical Newtonian gravitation) and a gravitomagnetic (Heaviside's prediction) field. The magnetic effects in gravitation are more commonly known as the Lense-Thirring or frame dragging effect describing precision forces of rotating masses orbiting each other. NASA's mission Gravity Probe B will look for experimental evidence of this effect. Similar to electrodynamics, a variation in gravitomagnetic fields induces a gravitoelectric (non-Newtonian) field and hence provides the possibility to modify gravitation.

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Since both gravitation and electromagnetism have the same source, the particle, the authors recently published a paper evaluating coupling constants between both fields[5] based on the charge-to-mass ratio of the source particle. This paper will review the coupling between gravitation and electromagnetism and point out the limits of present day technology and the expected order of magnitude of non-Newtonian gravitational fields that can be created by this method. Possible amplification mechanism such as ferro-gravitomagnetism and more speculative work published in the literature will be reviewed.

The principle of equivalence in the limit of weak gravitational fields (the gravitational Larmor theorem) will be explored and a possible new effect (the gravitomagnetic Barnett effect) recently suggested by the authors is discussed[6]. However the direct detection of this effect is pending on the possibility to have materials with high gravitomagnetic susceptibility. Nevertheless we show that the principle of equivalence in the weak field approximation together with the gravitational Poynting vector associated with induced non Newtonian gravitational fields (through angular acceleration) account properly for the conservation of energy in the case of cylindrical mass with angular acceleration. This is an encouraging result regarding the possible detection of macroscopic non-Newtonian gravitational fields induced through the angular acceleration of the cylinder in the region located outside the rotating cylinder. The detection of these non-Newtonian gravitational fields outside the cylinder would represent an indirect evidence of the existence of the gravitomagnetic Barnett effect.

Finally the free fall of a massive cylinder carrying electric charge is studied. It is shown that in order to comply with the law of conservation of energy, and with the equivalence principle, the acceleration with which the cylinder will fall depends on its electric charge, its mass and its length.

If the last two effects exposed above are experimentally detected, a technology that can control the free fall of bodies with mass in the laboratory is at hand. If the result is negative, a better empirical understanding of Einstein's general relativity theory in the limit of weak gravitational fields and when extended to electrically charged bodies, would have been achieved, which is a significant scientific result as well.

2. Maxwell Structure of General Relativity Theory

Einstein's field equation[7] is given by

$$R_{\alpha\beta} - \frac{1}{2} g_{\alpha\beta} R = \frac{8\pi G}{c^4} T_{\alpha\beta} \qquad (1)$$

During the linearization process, the following limitations are applied:

1. all motions are much slower than the speed of light to neglect special relativity
2. the kinetic or potential energy of all bodies being considered is much smaller than their mass energy to neglect space curvature effects
3. the gravitational fields are always weak enough so that superposition is valid
4. the distance between objects is not so large that we have to take retardation into account

We therefore approximate the metric by

$$g_{\alpha\beta} \cong \eta_{\alpha\beta} + h_{\alpha\beta} \qquad (2)$$

where the greek indices α, β = 0, 1, 2, 3 and $\eta_{\alpha\beta}$ = (+1, -1, -1, -1) is the flat spacetime metric tensor, and $|h_{\alpha\beta}| << 1$ is the perturbation to the flat metric. By proper substitutions and after some lengthy calculations[5] (the reader is referred to the literature for details), we obtain a Maxwell structure of gravitation which is very similar to electromagnetics and only differs due to the fact that masses attract each other and similar charges repel:

$$\begin{array}{ll}
div\,\vec{E} = \dfrac{\rho}{\varepsilon_0} & div\,\vec{g} = -\dfrac{\rho_m}{\varepsilon_g} \\
div\,\vec{B} = 0 & div\,\vec{B}_g = 0 \\
rot\,\vec{E} = -\dfrac{\partial \vec{B}}{\partial t} & rot\,\vec{g} = -\dfrac{\partial \vec{B}_g}{\partial t} \\
rot\,\vec{B} = \mu_0 \rho \vec{v} + \dfrac{1}{c^2}\dfrac{\partial \vec{E}}{\partial t} & rot\,\vec{B}_g = -\mu_g \rho_m \vec{v} + \dfrac{1}{c^2}\dfrac{\partial \vec{g}}{\partial t}
\end{array} \qquad (3)$$

Maxwell Equation (Electromagnetism) — Maxwell-Einstein Equation (Gravitation)

where $\vec{g}$ is the gravitoelectric (or Newtonian gravitational) field and $\vec{B}_g$ the gravitomagnetic field. The gravitational permittivity ε_g and gravitomagnetic permeability η_g is defined as:

$$\varepsilon_g = \frac{1}{4\pi G} = 1.19\text{x}10^{9}\,\frac{\text{kg}\cdot\text{s}^2}{\text{m}^3} \qquad (4)$$

$$\mu_g = \frac{4\pi G}{c^2} = 9.31\text{x}10^{-27}\,\frac{\text{m}}{\text{kg}} \qquad (5)$$

by assuming that gravitation propagates at the speed of light c. Although not unusual, this assumption turns out to be very important. Only if gravity propagates at c the Maxwell-Einstein equations match the ones obtained from adding necessary terms to Newtonian gravity to conserve momentum and energy[3].

Moreover, the authors could show that with this set of equations, the advance of the Mercury perihelion – one of the most successful tests of general relativity – can be calculated giving the exact prediction than without linearization[8]. This is a very surprising result because the advance of Mercury's perihelion is attributed to a space curvature in general relativity (Schwarzschild metric) which we neglected in our linearization process. The assumption of c as the speed of gravity propagation also implies that the Lorentz force law and the gravitomagnetic potential energy differ from their electromagnetic counterparts by a factor of four[8]. Therefore some authors[4] use $c/2$ as the speed of gravity propagation to get a gravity Lorentz force law similar to electromagnetics.

The Einstein-Maxwell equations allow to clearly see the gravitomagnetic component of gravitation and the possibility to induce non-Newtonian gravitational fields. Their close relation to electrodynamics allow to transform electromagnetic calculations into their gravitational counterparts[9].

3. Coupling of Electromagnetism and Gravitation in General Relativity

By comparing gravitation and electromagnetism in Equation (3), we see that both fields are coupled by the e/m ratio of the field source and we can write:

$$\begin{aligned} \vec{g} &= \kappa \cdot \vec{E} \\ \vec{B}_g &= \kappa \cdot \vec{B} \end{aligned} \tag{6}$$

using the coupling coefficient κ

$$\kappa = -\frac{m}{e}\frac{\mu_g}{\mu_0} = -\frac{m}{e}\frac{\varepsilon_0}{\varepsilon_g} = -7.41 \mathrm{x} 10^{-21} \cdot \frac{m}{e} \tag{7}$$

Obviously, this coefficient is very small and gravitational effects associated with electromagnetism have never been detected so far[10]. By combining Equation (6) with Equation (3), we see how both fields can induce each other:

$$\begin{aligned} rot\,\vec{E} &= -\frac{1}{\kappa}\frac{\partial \vec{B}_g}{\partial t} \\ rot\,\vec{B} &= \frac{e}{m}\mu_0 \rho_m \vec{v} + \frac{1}{\kappa}\frac{1}{c^2}\frac{\partial \vec{g}}{\partial t} \end{aligned} \tag{8}$$

Coupled Maxwell-Einstein Equations (Gravitation→Electromagnetism)

$$\begin{aligned} rot\,\vec{g} &= -\kappa \frac{\partial \vec{B}}{\partial t} \\ rot\,\vec{B}_g &= -\frac{m}{e}\mu_g \rho \vec{v} - \kappa \frac{1}{c^2}\frac{\partial \vec{E}}{\partial t} \end{aligned} \tag{9}$$

Coupled Maxwell-Einstein Equations (Electromagnetism→Gravitation)

For an electron in a vacuum environment κ=4.22x10^{-32} kg/C. For example, let us consider an infinitely long coil as shown in Figure 1.

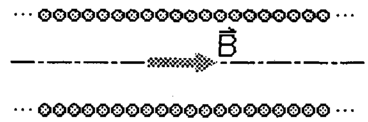

Figure 1 Magnetic Field Induced in a Coil

The magnetic field induced in the center line is then

$$B = \mu_0 I n \tag{10}$$

where I is the current and n is the number of coil wounds per length unit. For a current of 10,000 Ampére and 1,000 wounds per meter, the magnetic field would be B=12.56 T which is state of the art. The corresponding gravitomagnetic field is then B_g=5.3x10^{-31} s^{-1}. Even using a coil with 100,000 wounds to induce an electric field, the amplitude of the resulting gravitational field would only be in the order of g=10^{-26} ms^{-2}. This is much too small to be detected by any accelerometers having measurement thresholds of 10^{-9} ms^{-2}. By using heavy ions in a plasma instead of electrons we can increase the m/e ratio by 6 orders of magnitude, however, the magnetic fields to contain such a plasma transmitting a similar current of 10,000 Ampére are out of reach.

Nevertheless, although the induced gravitational fields are very small, in principle it is possible to create non-Newtonian gravitational fields along the same principles as we are used to in electromagnetism.

4. Amplification Mechanisms

Since all these electromagnetic-gravitational phenomena are so small, how can we amplify the coupling coefficient in order to obtain measurable non-Newtonian fields?

4.1 Gravitation-Magnetism

Similar to para-, dia-, and ferro-magnetism, the angular and spin momentums from free electrons in material media could be used to obtain a gravitomagnetic relative permeability μ_{gr} which increases the gravitomagnetic field $\vec{B}_g$. Since an alignment of magnetic moments causes also an alignement of gravitomagnetic moments, the gravitomagnetic susceptibility will be the same as the magnetic susceptibility in a magnetized material[5]

$$\chi_g = \chi \tag{11}$$

For our example of the coil in Figure 1, a ferromagnetic core would accordingly increase the gravitomagnetic field and induced non-Newtonian gravitational field by three orders of magnitude. Although significant, the resulting fields are still too low to be detected.

4.2 Coupling of Charge and Mass

All our discussions up to now are based on a coupling at the source particle by the e/m ratio. However, an additional coupling between charge and mass of the source itself might exist and provide a significant amplification mechanism.

Well accepted peer-review journals like Nature and Foundations of Physics featured articles on this topic describing experiments that suggest a coupling between charge and mass in combination with rotation (or acceleration, movement in general).

Dr. Erwin Saxl published an article[11] reporting a period change of a torque pendulum if the pendulum was charged. A positive charge caused the pendulum to rotate slower than when it was charged negatively. Figure 3 shows his observations with a small asymmetry of the period change between positive and negative potentials applied to the pendulum. The period is expressed by

$$T = \text{Constant} \cdot \sqrt{\frac{m}{g}} \qquad (12)$$

where m is the mass of the pendulum and g the Earth's gravitational acceleration. Assuming that g is not changed (it is highly improbable that the whole Earth is affected), Saxl's measurement can be interpreted as a change of the pendulum's mass by applying an electric potential to it.

Prof. James Woodward from the University of California reported experiments of accelerating masses that, on the other hand, charged up according to their mass and speed of rotation. His experiments were done both for rotating masses[12] as well as for linear accelerated test bodies[13]. Published in the Foundations of Physics and General Relativity and Gravitation, he suggested a broader conservation principle including mass, charge and energy. Results of a test body hitting a target and inducing a charge are shown in Figure 4. His results follow

$$q' \cong \text{Constant} \cdot m \cdot a \qquad (11)$$

where q' is the induced charge, m the test mass and a the acceleration (from rotation or calculated from the impact velocity).

Hence, both Saxl and Woodward experimentally reasoned a relationship between charge, mass and acceleration. A combination of all these factors to reduce/increase the weight of a body is described in a patent by Yamashita and Toyama[14]. A cylinder was rotated and charged using a Van der Graff generator. During operation the weight of the rotating cylinder was monitored on a scale. The setup is shown in Figure 5. If the cylinder was charged positively, a positive change of weight up to 4 grams at top speed was indicated. The same charge negative produced a reduction of weight of about 11 grams (out of 1300 grams total weight). This is an asymmetry similar to the one mentioned by Saxl[11]. Also the relationship between charge, rotation and mass is similar to Saxl and Woodward. The experimentors note that the weight changed according to the speed of the cylinder ruling out electrostatic forces, and that it did not depend on the orientation of rotation ruling out magnetic forces. The reported change of weight (below 1 %) is significant and indicates a very high order of magnitude effect.

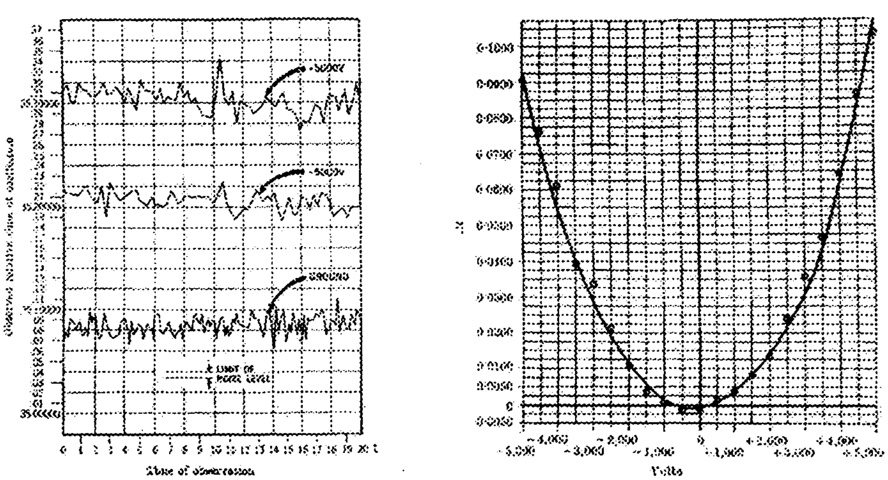

Figure 3 Change of Torque Pendulum Period vs. Applied Potential[11]

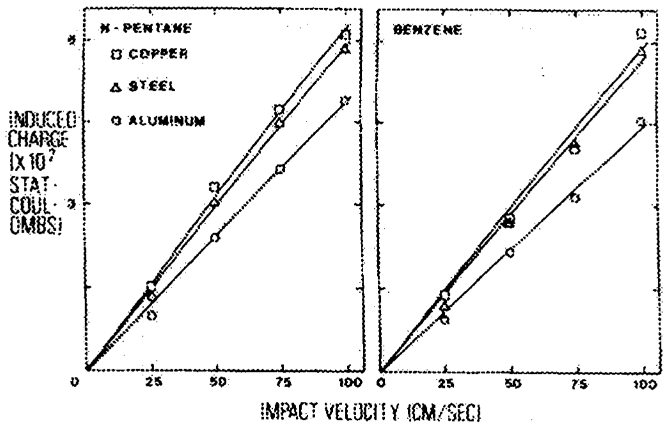

Figure 4 Charged Induced by Body Hitting Target[13]

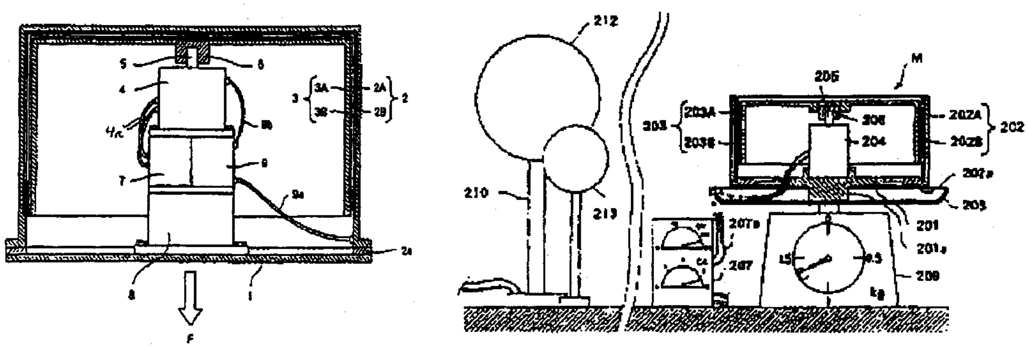

Figure 5 Setup of Charged Rotating Cylinder on Scale[14]

4.3 Alignment of Nuclear Spins

Henry Wallace, an engineer from General Electric, holds three patents on a method to produce a macroscopic gravitomagnetic and gravitational field by aligning nuclear spins due to rotation[15-17]. He claims that if materials with a net nuclear half-spin (one neutron more than protons in the nucleus) are rotated, this nuclear spin is aligned and produces a macroscopic gravitational effect. This is in fact similar to the Barnett effect where a metal rod is rotated and magnetisation of the material is observed. However, macroscopic magnetism in electromagnetism is caused by spin alignment of electrons, nuclear magnetism plays a very minor role due to the much higher mass of a proton or neutron compared to the electron. In a gravitational context the difference in mass is no major drawback anymore and nuclear magnetism should be on the same order of magnitude than electron magnetism. Usually, very low temperatures in the order of nano Kelvin are required to align nuclear spins, simple rotation would be much more easy.

The contribution of neutron spins to gravitomagnetic fields is theoretically on the order of ferromagnetism[5]. However, since Wallace claims to have measured at least the induction of nuclear spin alignment in a rotating detector material – by what he thinks a gravitomagnetic field, possible unknown amplification mechanisms (quantum gravity, nuclear strong force interaction) could cause much higher order of magnitude effects.

His setup is shown in Figure 6. A generator assembly (test mass rotating in 2 axis) is mounted on the left side and a detector assembly (similar to generator) is mounted on the right side with the possibility of rotation in the plane of the paper. A laser is monitoring the oscillations of this detector assembly. If both are rotated in the same orientation and counter wise, the laser detected a difference (Figure 7) which Wallace attributed to a force field. Since it only depended on the nuclear spin (e.g. Iron did not work but is a strong ferromagnetic material), Wallace ruled out magnetism as the origin of the force. In a different setup he showed that the field generated could constructively reduce the vibrational degrees of freedom of the crystal structure resulting in a change of its electrical properties (Figure 8).

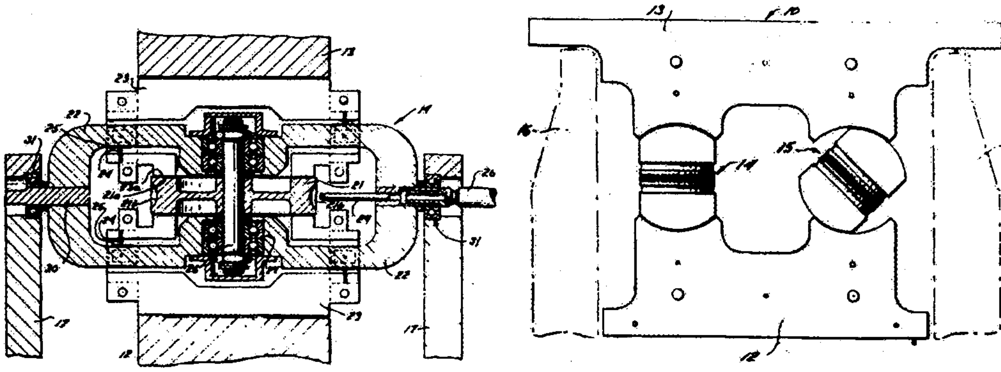

Figure 6 Setup of Rotating Test Mass (2 Axis) and Generator (Left) and Detector (Right) Position[15]

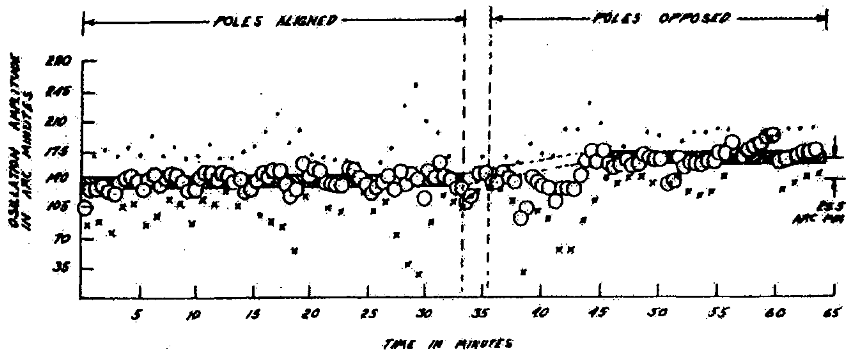

Figure 7 Oscillations of Detector Assembly[15]

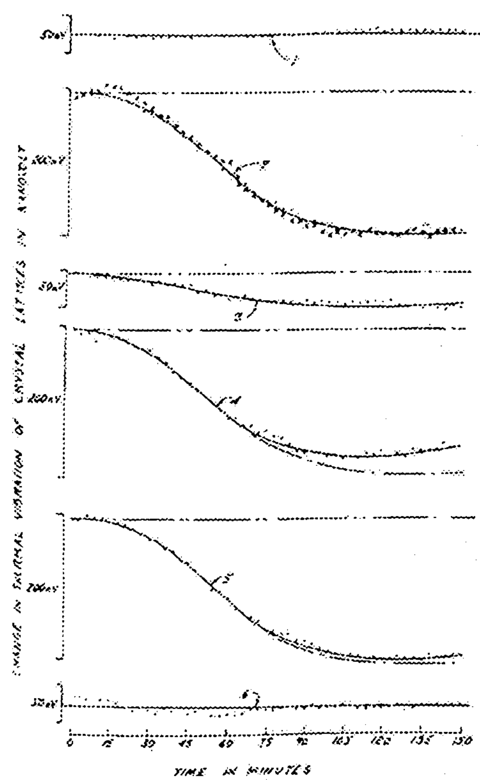

Figure 8 Change in Thermal Vibration of Crystal Lattices[15]

Hence, there is quite some experimental evidence for an amplification mechanism through nuclear magnetism to generate non-Newtonian gravitational fields using effects predicted by general relativity theory.

5. Principle of Equivalence and High-Order of Magnitude Non-Newtonian Gravitation

We explored the limits of inducing non-Newtonian gravitation using general relativity theory as well as looking at possible and speculative amplification mechanisms. Let us go back to the foundation of gravitation itself and explore the principle of equivalence in the limit of weak gravitational fields.

Einstein based his thoughts of gravitation on a famous Gedankenexperiment explaining the principle of equivalence: An observer can not distinguish between being inside a falling elevator or in a uniform gravitational field. Based on this equivalence, he developed the geometrical structure of general relativity. In the limit of weak gravitational fields, this simple Gedankenexperiment however is not complete as it covers only gravitoelectric fields and not the magnetic component of gravitation. According to the Larmor theorem of electromagnetics, a magnetic field can be replaced locally by a rotating reference frame with the Lamor frequency

$$\omega_L = \frac{1}{2}\frac{e}{m}B \tag{14}$$

The same argument applies for gravitation and a rotating reference frame rotating with the Lamor frequency can replace a gravitomagnetic field

$$\omega_{Lg} = -B_g \tag{15}$$

independent of the particle mass. The principle of equivalence[18] for weak gravitational fields (neglecting space curvature) also called gravitational Larmor theorem (GLT) should then be:

An observer can not distinguish between a uniformly accelerated ($\dot{\vec{v}}$) reference frame rotating with the gravitational Larmor frequency (ω_{Lg}) and a reference frame at rest in a corresponding gravitational field ($\vec{\gamma} = -\dot{\vec{v}}, \omega_{Lg} = -\vec{B}_g$).

But what happens if the speed of rotation of the elevator changes? According to the GLT, this would correspond to a change of a gravitomagnetic field flux and therefore induce a non-Newtonian gravitational component according to the gravitational Faraday law:

$$\varepsilon_g = \oint_\Gamma \vec{\gamma}\cdot d\vec{l} = -\frac{d\phi_{gm}}{dt} = -\frac{d}{dt}\oiint_\Sigma \vec{B}_g \cdot d\vec{\sigma} \tag{16}$$
$$= \frac{d}{dt}\oiint_\Sigma \vec{\Omega}\cdot d\vec{\sigma}$$

where $\vec{\gamma}$ is the non-Newtonian gravitational field, Γ and Σ are respectively the contour and surface of integration, ϕ_{gm} is the gravitomagnetic flux, $\vec{B}_g$ is the gravitomagnetic field, and $\vec{\Omega}$ is the angular velocity of the reference frame. If the observer measures this additional gravitational field the principle of equivalence holds and he can not distinguish between the elevator and the gravitational field. If he does not observe this effect, the gravitational Larmor theorem is not valid, as a weak field approximation to Einstein's general relativity theory. We will show later that these "induced" non-Newtonian gravitational fields contribute to account for the mechanical energy absorbed (dissipated) by a rotating body during the phase of angular acceleration (deceleration).

Suppose the gravitational Larmor theorem holds, every rotation corresponds to a gravitomagnetic field, which is many orders of magnitude higher than the gravitomagnetic field responsible for the precession forces in the classical Lense-Thirring effect.

5.1 Gravitomagnetic Barnett Effect

The authors discussed such rotational effect described as the gravitational Barnett effect[6]. In 1915 Barnett[19] observed that a body of any substance set into rotation becomes the seat of a uniform intrinsic magnetic field parallel to the axis of rotation, and proportional to the angular velocity. If the substance is magnetic, magnetization results, otherwise not. This physical phenomenon is referred to as *magnetization by rotation* or as the *Barnett effect.*

If a mechanical momentum with angular velocity Ω is applied to a substance, it will create a force on the elementary gyrostats (electrons orbiting the nucleus) trying to align them. This is equivalent to the effect of a magnetic field in this substance B_{equi} and we can write:

$$B_{equi} = -\frac{1}{g_l}\frac{2m}{e}\Omega \tag{17}$$

where g_l is the Landé factor for obtaining the correct gyromagnetic ratio. We can now apply the same argument to the gravitational case and postolate an equivalent gravitomagnetic field $B_{g\ equi}$ which counteracts the mechanical momentum:

$$B_{g\,equi} = -\frac{2}{g}\Omega \tag{18}$$

For an electron, $g_l=2$ and we see that physical rotation is indeed equivalent to a gravitomagnetic field. From Equation (18) we can compute the gravitomagnetization acquired by the rotating material:

$$\vec{M}_g = \frac{\chi_g}{\mu_{0g}}\vec{B}_{g\,equi} = -\frac{\chi_g}{\mu_{0g}}\frac{2}{g}\vec{\Omega} \qquad (19)$$

where χ_g is the garvitomagnetic susceptibility. Taking into account the coupling between gravitation and electromagnetism presented above we can demonstrate the general result:

$$\vec{M}_g = -\frac{\chi}{\mu_0}\frac{2}{g}\left(\frac{m}{e}\right)^2\vec{\Omega} \qquad (20)$$

where χ is the magnetic susceptibility of the material[6]. This indicates that the gravitomagnetic moment associated with the substance will be extremely small. Therefore we can not use this gravitomagnetic moment to induce macroscopic non-Newtonian gravitational fields. However we can show, following our discussion on the equivalence principle, that if the field of rotation in Equation (18) can not be distinguished from gravitomagnetism, it must be a real field which we can use to induce non-Newtonian gravitational fields. The detection of such fields would represent an indirect proof of the existence of the gravitomagnetic Barnett effect.

5.2 Gravitational Poynting Vector and Gravitational Larmor Theorem in Rotating Bodies with Angular Acceleration

The gravitational Poynting vector, defined as the vectorial product between the gravitational and the gravitomagnetic fields, $\vec{S}_g = \frac{c^2}{4\pi G}\vec{\gamma}\times\vec{B}_g$, provides a mechanism for the transfer of gravitational energy to a system of falling objects (we will consider in the following a cylindrical mass m, with radius a and length l). It has been shown[20] that using the gravitational Poynting vector, the rate at which the kinetic energy of a falling body increases is completely accounted by the influx of gravitational field energy into the body. Applying the gravitational Larmor Theorem (GLT) to a body with angular acceleration. We get that a time varying angular velocity flux will be associated with a non-Newtonian gravitational field proportional to the tangential acceleration. The gravitational electromotive force produced in a gyrogravitomagnetic experiment can be calculated using the gravitational Faraday induction law as given in Equ (16). Together with the GLT expressed through Equation (15) we get

$$\varepsilon_g = \frac{d}{dt}\oiint_\Sigma \vec{\Omega}\cdot d\vec{\sigma} \qquad (21)$$

The induced non-Newtonian gravitational field associated with this gravitational electromotive force is at the surface of the cylinder is:

$$\oint_\Gamma \vec{\gamma}\cdot d\vec{l} = \frac{d}{dt}\oiint_\Sigma \vec{\Omega}\cdot d\vec{\sigma} \qquad (22)$$

$$\vec{\gamma}_\theta = \frac{1}{2}a\dot{\Omega}\,\hat{e}_\theta \qquad (23)$$

From this non-Newtonian gravitational field and the gravitomagnetic field produced by the rotating mass current, we can compute a gravitational poynting vector

$$\vec{S}_{g\Omega} = \frac{c^2}{4\pi G}\vec{\gamma}_\theta\times\vec{B}_{g\Omega} = \frac{1}{4\pi}\left(\frac{a}{a+\ell}\right)\Omega\dot{\Omega}m\,\hat{n} \qquad (24)$$

which will also provide an energy transfer mechanism to explain how massive bodies acquire rotational kinetic energy when mechanical forces are applied on them[21]. The rate at which the rotational kinetic energy of a body increases (or decreases) due to the application of external mechanical forces on that body, is completely accounted by the influx (out-flux) of gravitational energy into (outward) the body.

$$\left.\frac{dU}{dt}\right|_\Omega = S_{g\Omega}(2\pi a^2 + 2\pi a\ell) = \frac{d}{dt}\left(\frac{1}{2}I\Omega^2\right) \qquad (25)$$

where I, is the moment of inertia of the cylinder. This demonstrates the validity of the gravitational Larmor theorem, and shows how the transfer of mechanical work to a body can be interpreted as a flux of gravitational energy associated with non-Newtonian gravitational fields produced by time varying angular velocities. This is an encouraging result regarding the possible detection of macroscopic non-Newtonian gravitational fields induced through the angular acceleration of the cylinder in the region located outside the rotating cylinder. The non-Newtonian gravitational field outside the cylinder is given by:

$$\gamma = \frac{1}{2}\frac{a^2}{r}\dot{\Omega} \qquad (26)$$

where $r > a$ is the distance from the cylinder's longitudinal axis. For $r \le a$ we have, $\gamma = 0.5\times a\dot{\Omega}$. For the following values of r=1 m, a=0.1 m, $\dot{\Omega} = 200$ Hz/s, γ will have the value of 1 ms^{-2}. We recommend that experiments shall be performed with the aim of evaluating Equation (26).

Is it possible to use fluxes of radiated electromagnetic energy to counteract the effect of absorbed fluxes of gravitational energy? That is a question Saxl, Woodward and Yamashita tried to evaluate empirically. These empirical approaches shall be complemented in the following by a theoretical analysis of the net energy flow associated with the free fall of an electrically charged cylindrical mass.

5.3 Free Fall of a Cylindrical Mass Electrically Charged

A cylindrical mass electrically charged in free fall must comply with the law of conservation of energy and with the principle of equivalence[22]. During the free fall the cylindrical mass will absorb gravitational energy, which is described by the following gravitational Poynting vector:

$$\vec{S}_g = \frac{c^2}{4\pi G}\vec{\gamma}\times\vec{B}_g = \frac{mv\gamma}{2\pi a\ell}\hat{n}_{in} \qquad (27)$$

where v is the speed of the cylinder while it is falling, γ is the Earth gravitational field, m, a, l are respectively the mass, length and radius of the cylinder and $\hat{n}_{in}$ is a unit vector orthogonal to the surface of the cylinder and Poynting inwards. The cylinder due to its electric charge will also radiate electromagnetic energy according to the following electromagnetic Poynting vector:

$$\vec{S}_{em} = \frac{1}{\mu_0}\vec{B}\times\vec{E} = \frac{\mu_0}{8\pi^2}\frac{Q^2 v\dot{v}}{a\ell(a+\ell)}\hat{n}_{out} \qquad (28)$$

where Q is the electric charge carried by the cylinder, μ_0 is the magnetic permeability of vacuum and $\hat{n}_{out}$ is a unit vector orthogonal to the surface of the cylinder and Poynting outwards. The principle of equivalence states that if the cylinder is at rest with respect to a reference frame which is uniformly accelerating upwards (with respect to the laboratory) with acceleration $\vec{v} = \gamma\hat{e}_z$, the cylinder will radiate (with respect to the laboratory) according to the following Poynting vector:

$$\vec{S}_{em} = \frac{1}{\mu_0}\vec{B}\times\vec{E} = \frac{\mu_0}{8\pi^2}\frac{Q^2 v\gamma}{a\ell(a+\ell)}\hat{n}_{out} \qquad (29)$$

Therefore to comply with the principle of equivalence, we shall take in Equation (28) $\dot{v} = \gamma$ [23].

The sum of both energy fluxes in Equations (27) and (29) must comply with the law of conservation of energy. Therefore the Sum of gravitational incoming flux and the radiated electromagnetic energy flux must be equal to the rate at which the kinetic energy of the body varies in time.

$$S_{em}\left(2\pi a^2 + 2\pi a\ell\right) + S_g 2\pi a\ell = \frac{d}{dt}\left(\frac{1}{2}mv^2\right) \qquad (30)$$

From Equation (30) we deduce that the acceleration with which the electrically charged cylindrical mass will fall is:

$$\dot{v} = \gamma\left(1 - \frac{\mu_0}{4\pi}\frac{Q^2}{m\ell}\right) \qquad (31)$$

Equation (31) shows that the free fall of an electrically charged body would violate the law of Galilean free fall, because the acceleration of fall would depend on the electric charge, size and mass of the falling body. The fact that the acceleration of fall depends on the square of the electric charge rules out the possibility to explain with the present analysis, the observations of Saxl and Yamashita, regarding the increase of mass for positively charged bodies and the decrease of mass for negatively charged bodies. Notice that following the rational which leads to equation (31), the phenomenon described by this equation should happen either in a reference frame at rest in an external gravitational field or inside a uniformly accelerated reference frame, therefore we are not able to use this phenomenon to distinguish between both situations. Consequently equation (31) do not violate the principle of equivalence. To test equation (31) we propose to measure the time of fall of charged cylindrical capacitors, and compare it with the time of fall of similar uncharged capacitors. For m=10 grams, l=10 cm, Q=100 C, we will have $\dot{v} = 0$. For these values the cylinder would not be able to fall! However to avoid disruption currents for such a high value of electric charge is a technological challenge.

Conclusion

In the present work we did an extensive review of possible "classical ways" to induce non-Newtonian gravitational fields from electromagnetic phenomena or by using the principle of equivalence in the limit of weak gravitational fields. If the experiments performed by Saxl, Yamashita, Woodward and Wallace were reproducible this would represent a breakthrough in the possibility to control gravitational phenomena at the laboratory scale. The understanding of the principle of equivalence for electrically charged bodies and in the limit of weak gravitational fields is crucial to evaluate respectively:

- the possibility of directly convert gravitational energy into electromagnetic energy during the free fall of an electrically charged body.
- the possibility of inducing non-Newtonian gravitational fields through the angular acceleration we might communicate to solid bodies.

The experimental confirmation of such phenomena would be a dramatic step forward in the technological control of free fall. The non detection of the presented phenomena could lead to a better empirical understanding of Einstein's general relativity theory in the limit of weak gravitational fields and when extended to electrically charged bodies, which is a significant scientific result as well. These experiments could also contribute to decide which approach to weak gravity is the correct one, i.e. linearized general relativity or the extension of Newton's laws to time dependent systems.

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Abstract

This article summarises some of the current activities of the gravitational research group above. After surveying the role of gauge fields as carriers of the basic forces in physics and the momentum conservation constraints placed on current propulsion technology a number of alternative strategies, under active investigation, are briefly discussed. The essential theme is the detection of hitherto undetected components of gravitation that may have implications for the motion of matter. Such components include gravito-magnetic fields and radiation modes as well as new scalar interactions resulting from various proposals for the unification of gravitation with the other basic forces. Experiments are suggested that may shed light on the existence of novel gravitational interactions. These include the detection of transient gravitational fields by means of orbiting Cosserat antennae and the effects of torsional forces on the perihelion shift of planets.

1 Forces and Physics

The effective exploration of interplanetary systems and beyond demands advances in propulsion technology. Our visionaries tell us that the pace of development will be interrupted by sudden advances analogous to the past discoveries of manned flight and reciprocating combustion, gas turbine and rocket engines. Besides "technological breakthroughs" there is also a hope that new "conceptual breakthroughs" in the foundations of physics will offer new perspectives as guides in the search for new technologies. Harnessing the power of the electromagnetic field had to wait for Faraday and Maxwell and the development of nuclear power sprang from an understanding of the quantum nature of matter and the relativistic structure of space-time. History teaches one that major developments in science and engineering are not always predictable within the context of the prevailing wisdom of the time.

Modern physics continues to power technology on many fronts. Much of this development springs from the quantum nature of matter and radiation. By contrast gravitation defies a unique and consistent quantum formulation. Its most elegant formulation is in terms of the classical geometrical properties of space-time and it is related to the other interactions in nature at the level of classical physics. Here classical fields are the primary structures and matter is modelled as "crystallised field energy". Such concentrations of energy owe their existence to the basic quantum laws of nature but classical laws are often adequate to describe the interactions of such matter with fields on a macroscopic level. These interactions depend on a small number of physical attributes such as inertial mass and interaction strengths ("charges") that enter into the classical field equations. These are expressed as tensor equations on a dynamic space-time in general. Thus electromagnetic fields couple to electric charge, nuclear force fields to colour charge, the forces responsible for radioactivity to weak-hypercharge and the mass-energy of all fields to gravity. The significance of different force fields in any particular situation is in large measure determined by the relative sizes of these couplings. This follows since most basic laws follow remarkable mathematical similarities. See Figure 1. They are all associated with symmetries of mathematical patterns (Lie groups) with field

Interaction	Mediating Quanta	Lie Group	Connection	Dynamics
Electromagnetic: Electric charge	QED: Photon	U(1)	$\mathbf{A}_6$	$\mathbf{F} = d\,\mathbf{A}_6$ $d \star \mathbf{F} = \mathbf{J}[\Phi, \mathbf{A}_6]$
Electroweak: Hypercharge	QAD: W and Z Bosons	SU(2) × U(1)	$\mathbf{A}_4$	$\mathbf{F} = d\,\mathbf{A}_4 + [\mathbf{A}_4, \mathbf{A}_4]$ $D \star \mathbf{F} = \mathbf{J}[\Phi, \mathbf{A}_4]$
Strong: Colourcharge	QCD: Gluons	SU(3)	$\mathbf{A}_3$	$\mathbf{F} = d\,\mathbf{A}_3 + [\mathbf{A}_3, \mathbf{A}_3]$ $D \star \mathbf{F} = \mathbf{J}[\Phi, \mathbf{A}_3]$
Gravity: Mass-energy and spin	QG: Graviton	Spin(3,1)	$\mathbf{A}_5$	$\mathbf{F} = d\,\mathbf{A}_5 + [\mathbf{A}_5, \mathbf{A}_5]$ $E[g, \mathbf{A}_5] = T[g, \Phi, \mathbf{A}_6, \mathbf{A}_5, \mathbf{A}_3, \mathbf{A}_4]$

Figure 1: *This table classifies the known force fields in terms of their attributes. Each can be associated with a mathematical symmetry (Lie group) that determines how the fields interact with themselves, other force fields and matter at each event in space-time. The precise coupling to matter is determined by different kinds of charge. Thus electrically charged particles couple to the electromagnetic field, colour charged particles to the chromodynamic nuclear field and weak-hypercharged particles to the electro-weak fields responsible for radioactive decay. At the quantum level these fields are mediated by field quanta; photons, gluons and W-Z bosons respectively. All matter and fields with mass-energy couple to gravity. It is expected that the quanta of gravitational waves (gravitons) will be responsible for a theory of quantum gravity. The dynamics of all these fields have many similarities (they arise from "connections associated with Lie groups") although gravitation occupies a unique position in classical physics since it is intimately related to the structure of space and time itself.*

strengths defined in terms of directions ("connections") in collections of mathematical structures at each event in space-time. The gravitational field is similarly determined by a field strength associated with a Lie group although according to Einstein its field equation breaks the mould set by the other force fields in nature. This difference is accentuated by the recognition that relativistic gravitation may be formulated in terms of space-time geometry, an idea that has had profound implications for cosmogony and cosmology.

1.1 Propulsion Constraints

Given a propulsion unit, its effectiveness can usually be gauged from the laws of *classical* physics. In most cases forces on matter are prescribed and Newtonian dynamics is in principle adequate to describe the subsequent motion. For propulsion in the vicinity of the earth the earth's gravitational field (along with lift and drag of the air) is omni-present and propulsion forces are derived from the rate of change of momentum between "fuel" and "propelled system". If propellant is to be ejected as radiation or systems achieve speeds that are an appreciable fraction of the speed of light c, Newtonian dynamics is inadequate and must be replaced by the more accurate relativistic equations of motion.

A great deal can be learnt about the demands of enhanced propulsion proposals by elementary considerations based on well established physical principles[1]. It is inconceivable that the constraints imposed by such principles will require dramatic refinement by future scientific developments.

It is useful to distinguish between propulsion systems that must operate in the vicinity of the earth's surface and those in which Newtonian gravitational fields are negligible. With current technology expensive multi-stage chemical propellants are required to place structures into earth orbit and beyond. For a single propulsion system of mass $M(t)$ and speed $V(t)$ at time t, lifting vertically off the surface of a non-rotating earth with zero initial velocity and ejecting mass at a speed u_0 relative to the propelled system, $V(t)$ is given by

$$V(t) = -u_0 \log \frac{M(0)}{M(t)} - gt \qquad (1)$$

in a region where the acceleration due to gravity g may be considered constant. If the rate of mass ejection is constant one may eliminate the burn time $t = t_b$ given the specific thrust ratio $\mathcal{R} = 1 + \frac{\mathcal{A}}{g}$ where $\mathcal{A}$ is the initial acceleration of the system at lift off. Then

$$\frac{V(t_b)}{V_{esc}} = \frac{u_0}{V_{esc}} \left\{ \log \frac{M(t_b)}{M(0)} + \frac{1}{\mathcal{R}} \left(1 - \frac{M(t_b)}{M(0)} \right) \right\}$$

where V_{esc} is the escape velocity for the earth. Figure 2 shows $V(t_b)/V_{esc}$ versus $M(t_b)/M(0)$ for three values of u_0/V_{esc} appropriate for chemical propellants for both $\mathcal{R} = 1$ and $\mathcal{R} = 2$. These estimates set a benchmark for any new terrestrial propulsion system that claims to improve current multi-staging and chemical propellant technology.

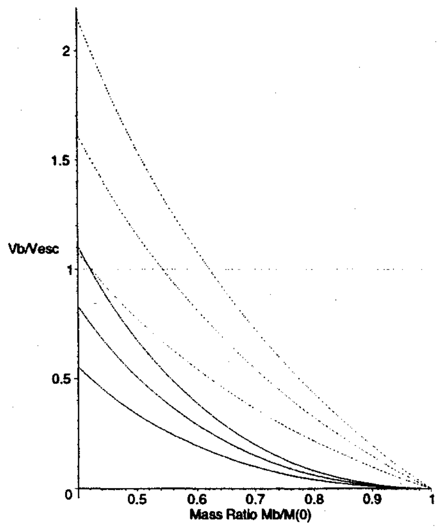

Figure 2: These plots indicate the mass ratio $M(t_b)/M(0)$ required to reach a non-relativistic speed V_b in the presence of the earth's (uniform) gravitational field. V_{esc} is the escape velocity for the earth. The upper three (dotted) curves correspond to a specific thrust parameter $\mathcal{R} = 2$. The lower three (full) curves correspond to $\mathcal{R} = 1$. In each triplet the ejection speed is chosen to vary according to three typical chemical propellants.

1.2 Relativistic Rockets

In an extra-terrestrial environment where Newtonian gravitational fields are negligible the system dynamics are different. To accommodate relativistic mass-energy ejection one has from consideration of rectilinear relativistic impulse dynamics in an inertial frame:

$$\lim_{\Delta t \mapsto 0} \frac{p_{t+\Delta t} - p_t}{\Delta t} = 0 \tag{2}$$

where the 4-momenta of the composite system are respectively

$$p_t = \Pi(V, M), \tag{3}$$

and

$$p_{t+\Delta t} = \Pi(V + dV, M + dM) + \Pi\left(\frac{V + dV - u_0}{1 - \frac{u_0(V+dV)}{c^2}}, dm\right) \tag{4}$$

for

$$\Pi(V, M) = \frac{M}{\left(1 - \frac{V^2}{c^2}\right)^{1/2}}[c, V, 0, 0]. \tag{5}$$

Taking the limit in (2) and eliminating dm yields:

$$\frac{1}{M(t)}\frac{dM(t)}{dt} = -\frac{dV(t)}{dt}\frac{1}{u_0(1 - \frac{V^2}{c^2})} \tag{6}$$

where $V(t)$ is the speed of the system relative to an inertial frame with clock time t. Here u_0 is the mass-energy ejection speed relative to the system at any ejection event. If the initial speed of the system is $V(0)$ in the inertial frame and u_0 is constant then at any time $t > 0$ where mass-energy ejection continues it follows that:

$$\frac{V(t)}{c} = \frac{1 - \alpha\mu(t)^\lambda}{1 + \alpha\mu(t)^\lambda} \tag{7}$$

where $\alpha = \left(1 - \frac{V(0)}{c}\right) / \left(1 + \frac{V(0)}{c}\right)$, $\mu(t) = M(t)/M(0)$, $\lambda = 2u_0/c$. This reduces to (1) for $g = 0$ when $c \mapsto \infty$. For chemical propellants with $u_0 \simeq 10$ km/sec, $M(t) \simeq 1$ ton and for a final speed $V(t) \simeq c/2$ this implies $M(0) \simeq 10^{7000}$ tons! In Figure 3, V/c is plotted against the mass ratio μ for any t for $V(0) = 0$ and varying values of u_0/c.

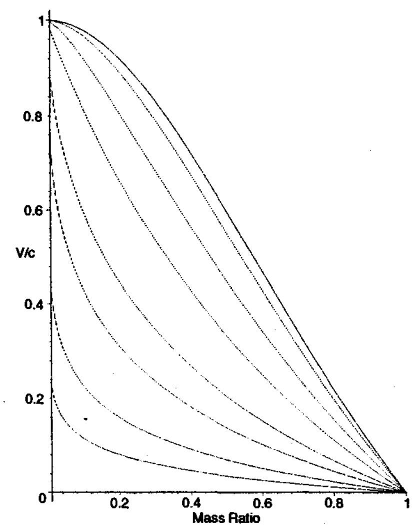

Figure 3: These plots indicate the mass-energy ratio $M(t)/M(0)$ required to reach a relativistic speed ratio V/c in the absence of any gravitational field. Each curve has a definite ejection speed ratio u_0/c relative to the propulsion system. These are 1/20,1/10,1/5,3/10,1/2,7/10 and 9/10 in order starting from the bottom of the plot. The advantage of relativistic mass-energy ejection is apparent from these curves.

The advantages of high speed ejection $u_0 \mapsto c$ over non-relativistic mass ejection are apparent in this picture. To establish propulsion efficiency in such cases one needs to know how the ejection mass ratio μ varies with proper time τ (i.e.the time measured by an on board clock). This permits one to integrate equation (7) for the motion of the system. Even for on-board robots a consideration of non-destructive proper accelerations is clearly desirable. Writing $\mu(\tau) = \exp(-\rho(\tau))$ the rectilinear relativistic equations of motion (2) of the system become:

$$\frac{dx(\tau)}{d\tau} = c \sinh \frac{\lambda\rho(\tau)}{2} \tag{8}$$

$$\frac{dt(\tau)}{d\tau} = \cosh \frac{\lambda\rho(\tau)}{2}. \tag{9}$$

The second equation (9) relates the on-board passage of time measured by τ to a clock fixed in the inertial frame measuring t. An attractive solution can be found that gives the propulsion system a constant proper acceleration $\mathcal{A}$:

$$x(\tau) = \frac{c^2}{\mathcal{A}} \left\{ \cosh \frac{\mathcal{A}}{c}\tau - 1 \right\} \tag{10}$$

$$t(\tau) = \frac{c}{\mathcal{A}} \sinh \frac{\mathcal{A}}{c}\tau. \tag{11}$$

To achieve such a uniform proper acceleration the proper mass ejection rate is required to satisfy

$$\frac{d\rho(\tau)}{d\tau} = \frac{\mathcal{A}}{u_0}. \tag{12}$$

If a "photon" rocket ($u_0 = c$) could be produced to achieve an on-board mass-energy ejection system with $\mathcal{A} = g$ (9.8 m/sec/sec) for an interval of time τ_b then $\mu(\tau_b) = \exp(-\frac{g\tau_b}{c})$. One readily finds that $M(0) = M(\tau_b)\exp(\kappa)$ if τ_b is taken as κ years. These considerations have powerful implications given the scales of space and time compared to those of human existence. For a round trip to a neighbouring star by such a photon rocket with $\kappa \simeq 9$ one has $\exp(9) \simeq 8000$. Even a mass ratio on this scale in a compact unit raises severe issues of heat dissipation.

2 Alternative Strategies

An alternative approach is to restrict mass-energy ejection mechanisms to local control programmes and seek dynamical propulsion in terms of interactions between ambient fields and their associated charges. Thus the system may be regarded as spending most of its time "coasting" or "surfing" in space. Standard "coasting" in a gravitational field is often referred to as "free-fall" and the motion of some point in the system under such conditions can be used as a reference of zero proper acceleration. It would be a rare occurrence for space travel to be based entirely on free fall in an ambient gravitational field. Departure from such motion is often associated with non-gravitational forces. Like any surfer or swimmer, adjusting body configuration to the environment can optimise transport. Such manoeuvering require a local expenditure of energy. However it may be possible to mine this energy from the environment itself. A natural source in the solar system is the sun itself or power transmitted by microwave from orbiting space-stations. When these sources are not available recourse to other fields including the gravitational field itself may be necessary. Thus it is important to understand the interaction of fields and gravity with matter, particularly if the latter has an extended structure that can respond to the geometry of space-time.

2.1 Gravicraft

To illustrate a "swimming" mechanism one may explore the concept of the gravicraft. In 1968 Beletsky and Givertz [2, 3, 4] introduced this notion, powered by actively controlling the dimensions of an extended body in orbit. Effective rates of orbital elevation above the earth demanded eccentric orbits and tethered structures on the order of several thousand kilometers in extent. Similar systems [5, 6, 7, 8] have been proposed to enhance maneuverability without the intervention of chemical propellants and offer an attractive means of cargo transfer between orbiting stations and energy generation. However, most theoretical estimates of the transfer speed between orbits have remained disappointingly low despite the obvious advantages of relying on environmental energy sources such as solar radiation and gravitational tidal forces*. Gravicraft motion relies on its coupling to the tidal component of a gravitational field. For static gravitational fields the spatial dimension of a gravicraft is determined by the scale over which the field varies. We have recently devised[9] a new method of gravicraft propulsion by actively varying its instantaneous moment of inertia in a quasi-circular orbit. A primitive craft is composed of two massive bodies connected via a light tether whose length can vary between l_{max} and l_{min} by the use of powered winches inside the bodies. By varying the moment of inertia of such a rotating system it is possible to transfer energy between the spin and orbital angular momentum of the craft. If the cycle of tether length variation is chosen appropriately it is possible for the entire structure to gain lift in the gravitational field. In

*Another attractive feature of gravicraft structures controlled by tethers in the ionosphere is their potential for generating power from ambient magnetic fields. In 1996 NASA used a conducting tether connected to the space shuttle in order to generate electricity.

the static field of a spherical mass M an estimate of the average rate of height gain at radius r is given by:

$$\dot{r} = \frac{3(GM)^{1/2}}{4\pi\, r^{5/2}}(l_{max}^2 - l_{min}^2) \qquad (13)$$

where G is the Newtonian gravitational coupling constant. For a gravicraft in low earth orbit with a tether length varying between 50 and 10 km this yields $\dot{r} \simeq 300m/hr$ and if its mass is 10^3 kg it expends about 425 watts. This ascension rate is an order of magnitude greater than any previous gravicraft mechanism known to the authors. Although primitive, such a mechanism illustrates how one can in principle manoeuver matter in an ambient gravitational field by exploiting its interaction with the field gradient. It also shows that the smallness of G demands a significant sustained gradient field for this mechanism to offer a viable means of long term propulsion. It may however offer a viable means to transport cargo between space-stations in distinct orbits by taking energy from the sun.

2.2 Gravito-electromagnetism

Several authors have noticed that a subset of the Einstein equations when perturbed about flat spacetime can be written in a form that looks remarkably similar to Maxwell's equations with the Newtonian gravitational field corresponding to the *gravito-electric* field and mass-currents playing the role of electric currents. Since the laws of electromagnetism are well studied and understood this analogy has proved quite fruitful in the *gravito-electromagnetic* context particularly in astrophysical applications. Extended "astrophysical jet-structures" are now thought to have their origin in *gravito-electromagnetic* forces.

In[10] we have considered the *most useful way* to define the *gravito-electromagnetic* fields in terms of the perturbed components of the space-time metric. Different choices are often responsible for the location of odd factors of 4 that permeate the *gravito-electromagnetic* equations compared with the Maxwell equations. Such choices also have implications for the form of the induced *gravito-electromagnetic* Lorentz force (and torque) in terms of the *gravito-electromagnetic* fields that enter into the equation for the motion of a massive point (spinning) particle. By analogy with the covariant laws of electromagnetism in spacetime *gravito-electromagnetic* potentials and fields are then defined to emulate electromagnetic gauge transformations under substitutions belonging to the gauge symmetry group of perturbative gravitation. These definitions have the advantage that on a flat background, with the aid of a covariantly constant time-like vector field, a *subset* of the linearised gravitational field equations can be written in a form that is *fully analogous to Maxwell's equations* (without awkward factors of 4 and extraneous tensor fields). It is shown how the remaining equations in the perturbed gravitational system restrict the time dependence of solutions to these equations and thereby prohibit the existence of propagating vector fields. The induced *gravito-electromagnetic* Lorentz force on a test particle is evaluated by geodesic perturbation in terms of these fields together with the torque on a small gyroscope. It is concluded that the analogy of perturbative gravity to Maxwell's description of electromagnetism can be valuable for (quasi-) stationary gravitational phenomena but that the analogy has its limitations. The relevance of this work for propulsion is that the equation of motion for any massive particle with velocity $\mathbf{v}$ in a pure *gravito-electromagnetic* field $(\mathcal{E}, \mathcal{B})$ takes the form

$$\frac{d\mathbf{v}}{dt} = \frac{1}{4}\mathcal{E} + \mathbf{v} \times \mathcal{B} \qquad (14)$$

in close correspondence with the Lorentz force on electrically charged particles in the electromagnetic field $(\mathbf{E}, \mathbf{B})$. In the static field of the earth the term $\mathcal{E}/4$ is responsible for the Newtonian gravitational acceleration field. The accompanying gravito-magnetic force determined by $\mathcal{B}$ on mass currents has to date escaped detection, but along with propagating gravitational waves is thought to exist. A gyroscope in such a field with velocity $\mathbf{v}$ is predicted to precess at a rate $(\frac{3}{4}\mathbf{v} \times \mathcal{E} - \mathcal{B})/2$ independent of its spin. In 2002 the NASA satellite Gravity Probe B will be launched to measure this effect. Although such *gravito-electromagnetic* forces and torques are small in a terrestrial environment they can be made to accumulate and their detection could herald a new avenue of gravitational precision technology. In addition to the $\mathcal{E}$ and $\mathcal{B}$ *gravito-electromagnetic* fields the equations of Einsteinian gravitation involve a second degree symmetric tensor $\mathbf{\Sigma}$ that has no electromagnetic analogue. The *gravito-electromagnetic* fields couple to this tensor and produce non-Maxwellian terms in the *gravito-electromagnetic* force and torque equations. This suggests that the equations of motion for massive spinning particles in gravitational fields deserve closer scrutiny.

2.3 Orbiting Cosserat Detectors

We have begun an intensive study of the behaviour of slender visco-elastic structures in space.

Such structures can be used to convert tidal gravitational fields into heat and hence extract energy from gravitational fields.

They are also being studied with a view to using them as antennae for the detection of gravitational radiation. The orbital dynamics of slender loop structures, several km in length, are ideally suited to analysis by the simple theory of *Cosserat rods* [11]. Such a description offers a clean conceptual separation of the vibrations induced by bending, shear, twist and extension and the coupling between eigen-modes due to tidal accelerations can be reliably estimated in terms of the constitutive properties of each structure.

The proposal is to use (several) orbiting Cosserat structures in order to detect gravitationally induced displacement correlations from among unwanted sonic signals in the system. Each continuum structure can be tuned to the entire acceleration field of a gravitational wave and resonant response to circumferential excitations tuned to optimise power absorption from continuous or pulsed gravitational excitations. Different topologies (e.g. open spirals) yield alternative broadband non-resonant responses.

The detection of gravitational signals in the 1 Hz region would provide vital information about stochastic backgrounds in the early Universe and the relevance of super-massive black holes to the processes that lead to processes in the centre of galaxies. Such information can only enhance our understanding of the interaction of gravity and matter and test the predictions of many proposed generalisations of Einstein's description of gravitation.

2.4 Scalar Fields and Mass Generation

In section (1) it was stated that the structure of the basic interactions was related to a pattern of symmetry groups. For gravity the symmetry group of relevance encodes the invariance of the speed of light in space-time and the behaviour of particles with mass and intrinsic spin. One of the great advances in recent years has been the recognition that all these symmetries arise as approximations from a description of extended structures in higher dimensions and that space-time is a classical approximation to a more general quantum description that unites all the fields shown in Figure 1. Although this picture is incomplete there are indications that Einstein's original description of pure gravitation may need supplementing with additional fields. In particular, remnants of a higher symmetry group may persist on scales accessible to experiment. In this regime additional scalar fields seem inevitable. The role of such scalar fields can modify the short range behaviour of gravitation. It is therefore of importance to explore whether such fields can be detected experimentally and assess their significance on the behaviour of other matter.

One approach is to examine the manner in which residual symmetries for gravity are broken. We have recently shown [12] that the breakdown of local Weyl symmetry in a theory of gravity can be accommodated in the context of the standard model of particle interactions. A natural setting for this mechanism is a space-time geometry described by a connection with dynamical torsion and a metric that is not covariantly constant. Together with a scalar field such a connection encodes new gravitational interactions that can be reformulated in terms of the standard description of Einsteinian gravity. The emergence of space-time torsion, dependent on the gradient of the dynamic scalar field, is responsible for the appearance of the so-called *improved stress-energy tensor*. In the broken phase in which electro-weak phenomenology is discussed the theory gives rise to a Higgs particle with mass M_η and a new electrically neutral vector boson with mass M_Q such that

$$\frac{M_\eta^2}{M_Q^2} = \frac{8\lambda v^2}{\gamma}$$

in terms of the couplings in the theory. It is of interest to note that a number of grand unified models predict a new neutral vector boson and experimental data are now detailed enough to check for its existence. It appears that such data are better described if the presence of such a boson is assumed. The theory above has been analysed in a broken phase in which normal gravitation (based on metric perturbations about Minkowski space-time) is negligible. The mass generation mechanism has been connected with a component of non-Einsteinian gravitation associated with the Weyl connection Q. This forms part of the natural space-time geometry determined from an action principle and may be expected to give rise to new kinds of force on matter. If the neutral boson described by the excitation of the Weyl potential Q in Minkowski space-time can be observed in current electro-weak data it may signal that a new component of gravitation can influence phenomenology at energies well above the Planck scale.

2.5 Scalar Fields and Torsion Forces

In the scalar-tensor theory of gravitation formulated by Brans and Dicke[13], the motion of a test particle was originally assumed to be a "Levi-

Civita geodesic" associated with the metric derived from the Brans-Dicke field equations (even though the scalar field could vary in space-time). Later Dirac in [15] showed that in a Weyl invariant generalisation it was more natural to generate the motion of a test particle from a Weyl invariant action principle and that such a motion in general differed from a Brans-Dicke Levi-Civita geodesic. Although Dirac was concerned with the identification of electromagnetism with aspects of Weyl geometry even for neutral test particles it turns out that test particles would follow "auto-parallels" of a connection with torsion. We have shown[16] that the theory of Brans and Dicke[13] can be reformulated as a field theory on a space-time with dynamic torsion determined by the gradient of the Brans-Dicke scalar field Φ. Of course no new physics *of the fields* can arise from such a reformulation, although it does clarify certain issues relating to the conformal structure of the theory and its couplings to matter with intrinsic spin. However, the behaviour of spin-less *particles* in such a geometry with torsion depends on the choice made from two possible alternatives. One may assert that their histories are *either* geodesics associated with auto-parallels of the Levi-Civita connection *or* the auto-parallels of the non-Riemannian connection with torsion. Since one may find a spherically symmetric, static solution to the Brans-Dicke theory (in either formulation), it is possible to compare these alternatives for the history of Mercury about the Sun by regarding it as a spin-less test particle as in General Relativity.

To summarise the relevant equations of motion the language of covariant differentiation is appropriate. Differentiation involves a limiting procedure in which objects are compared at the same point. In ordinary calculus space has an "affine vector space structure" and there is a natural parallelism which permits vectors at different points to be transported to common points for comparison. Gravitation is formulated on a more general manifold. A manifold does not in general have a vector space structure and such a "natural parallelism" is absent. A new structure[†] called a "space-time connection", ∇ , is required to transport vectors from one point in the manifold to another, along an arbitrary curve.

The equation for a time-like auto-parallel is

$$\nabla_{\dot{C}}\dot{C}=0$$

where the 4-velocity $\dot{C}$ is normalised with respect to the space-time metric $\mathbf{g}$:

$$\mathbf{g}(\dot{C},\dot{C})=-c^2. \tag{15}$$

By expressing ∇ in terms of the Levi-Civita connection $\hat{\nabla}$ with $\tilde{V}=g(V,-)$ for any vector V one may write this as

$$\widetilde{\hat{\nabla}_{\dot{C}}\dot{C}}=-\frac{1}{2\Phi}i_{\dot{C}}(d\Phi\wedge\tilde{\dot{C}})$$

(the operator $i_{\dot{C}}$ denotes contraction of the 2-form with the vector $\dot{C}$) and interpret the right hand side as a torsion acceleration field analogous to the Lorentz force on electrically charged particles. Note however that the torsion force produces the same acceleration on all massive test particles. If $\dot{C}$ is parameterised in terms of proper time τ in any coordinates $x^\mu(\tau)$, the above is:

$$\frac{d}{d\tau}\left(\Phi^{1/2}\frac{dx^\mu}{d\tau}\right)+\Phi^{1/2}\left\{{}^{\mu}_{\nu\lambda}\right\}\frac{dx^\nu}{d\tau}\frac{dx^\lambda}{d\tau}$$

$$=-g^{\mu\nu}\frac{\partial_\nu\Phi}{2\Phi^{1/2}}. \tag{16}$$

To illustrate the effects of this equation of motion we have recomputed[17] the classical shift in the perihelion rate of Mercury's orbit about the Sun in terms of a static spherically symmetric solution of the vacuum Brans-Dicke field equations [13]. Taking into account that the speed of Mercury is non-relativistic and that its Newtonian orbit is much larger than the Schwarzschild radius $r_s=2GM/c^2$ of the Sun, one finds the perihelion shift per revolution Δ of the orbit:

$$\Delta=\frac{3\omega+5}{3\omega+6}\,\delta_\omega \tag{17}$$

where $\delta_\omega=3\lambda_\omega\pi$, $\lambda_\omega=r_s/\hat{r}_0$ and ω is the Brans-Dicke coupling parameter. Using the Kepler period

$$\hat{T}=2\pi(\hat{r}_0^3/(1-\hat{\epsilon}^2)GM)^{1/2},$$

the shift δ_ω may be expressed in terms of $\hat{T}$ and $\hat{\epsilon}$. This may be compared with the result based on the assumption that Mercury's orbit follows from a geodesic of the torsion-free Levi-Civita connection. In this case one finds

$$\Delta=\frac{3\omega+4}{3\omega+6}\,\delta \tag{18}$$

[†]Consider a curve C with tangent vector $\dot{C}$ and an arbitrary vector field X . An affine connection at a point p in space-time is a map that takes the pair $(\dot{C},X)$ to a new vector $\nabla_{\dot{C}}X$ at p, which is linear in $\dot{C}$, and satisfies

$$\nabla_{\dot{C}}(X+Y)=\nabla_{\dot{C}}X+\nabla_{\dot{C}}Y$$

$$\nabla_{\dot{C}}(\phi X)=\dot{C}(\phi)X+\phi\nabla_{\dot{C}}X$$

for all scalar fields ϕ and vector fields X,Y. Due to the $\dot{C}$ linearity $(\nabla X)_p$ is a (1,1) tensor at p with $(\nabla X)_p(\dot{C},\alpha_p)=\alpha_p(\nabla_{\dot{C}}X)$ for all covectors α_p at p. It is called the covariant differential of X at p.

where $\delta = 3\lambda\pi$ (with $\lambda = r_s/r_0$) is the perihelion shift per revolution of the orbit based on the Schwarzschild solution for the metric in General Relativity.

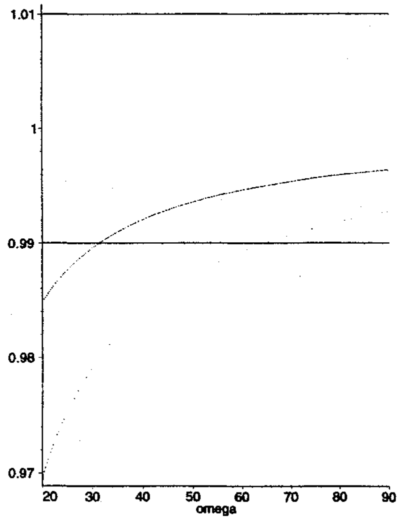

Figure 4: Behaviour of Δ/δ as a function of the Brans-Dicke coupling parameter ω. The full curve corresponds to a precession rate of Mercury's orbit under both metric and torsional acceleration. The lower dotted line corresponds to the original prediction of the Brans-Dicke theory. The experimental observations are consistent with Δ/δ lying between the full horizontal lines centered on $\Delta/\delta = 1$

Given the prominent role played by the motion of test particles in many astrophysical phenomena and the possibility of new gravitational interactions mediated by scalar fields we feel that, with the enhanced technology now available to modern space science, the possible relevance of scalar field induced space-time torsion should not be ignored. Should the departure of spin-less particles from Levi-Civita geodesic motion be detected in some purely gravitational environment it would indicate that matter has additional "gravitational charge" in addition to its mass and to its electromagnetic, weak and strong couplings to other fields in nature.

3 Summary

This article summarises some of the current activities of the gravitational research group above. Having surveyed the role of gauge fields as carriers of the basic forces in physics and the momentum conservation constraints placed on current propulsion technology a number of alternative strategies, under active investigation, have been briefly discussed. The essential theme is the detection of hitherto undetected components of gravitation that may have implications for the motion of matter. Such components include expected configurations of Einsteinian gravitation (including gravito-magnetic and radiation modes) as well as new scalar interactions resulting from various proposals for the unification of gravitation with the other basic forces. It would be premature to rank these strategies in terms of potential for the advancement of propulsion technology. International efforts are well advanced for the detection of gravitational radiation and the STEP experiment[18] is expected to place firm experimental bounds on the foundations of General Relativity. We have suggested above that there are also less expensive experiments that may also shed light on the existence of novel gravitational fields and that if scalar field gravitational interactions with matter can be detected they may offer unsuspected avenues for development.

4 Acknowledgement

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An Asymmetric Gravitational Wave Propulsion System

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AN ASYMMETRIC GRAVITATIONAL WAVE PROPULSION SYSTEM

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Abstract

Gravitational wave radiation is generated by the quadrapole moment of matter that is in motion. An analytical model is constructed to investigate the radiation pattern and radiated power of a single resonant vibrator cylinder, as compared to that of a phased linear array. The linear array is then evaluated in terms of phase relationship in order to create an asymmetry in the radiated pattern and hence a directional force. This is compared to the force of a solar sail in the earth orbital plane.

Introduction

Einstein[1] derived the weak-field solution of the gravitational wave in accordance with the general and special theories of relativity. This paper uses this scientific background to describe a revolutionary new approach to propulsion. Programmable laser diodes in conjunction with semiconductor materials will be used to generate a highly directional transverse wave gravitational wave (TWGW) radiator. This asymmetric TWGW radiator will create a directional force through the center of mass of the radiating system, thus forming a propellantless propulsion system.

Theoretical work indicates the ability to generate gravitational wave radiation through the quadrapole moment of matter under stress and strain. The radiation pattern is symmetric about the center of mass, and the direction of the pattern is at right angles to the stress and strain vector. The radiation pattern looks like a torus. The radiated power is very small (10^{-29}) watts); however, when a linear sequence of radiators is put together and their patterns are allowed to superimpose, the total radiated power can approach kilowatts. The asymmetry of the radiated pattern is produced by adjusting the phase of the radiators. The resulting power imbalance will produce a force through the center of mass of the radiators. In order to accomplish this task, high peak power laser diodes will be used to photo-accoustically drive thin-film resonators. It becomes imperative to understand the energy flow between the laser diode driving the resonator and the result in gravitational radiation from the radiator.

Theory

In order to establish an analytical background consider the following. Let $\eta_{\mu\nu}$ be a Lorentz metric, then the Riemannian metric is expressed as

$$g_{\mu\nu} = \eta_{\mu\nu}\sqrt{K}h_{\mu\nu} \tag{1}$$

as a first approximation under the weak-field assumptions, K is Einstein's constant. The potential of the field can be expressed as

$$\phi_{uv} = h_{uv} - \frac{1}{2}\eta_{uv}h \tag{2}$$

resulting in the form for 4-space

$$\Box\phi^{\alpha\beta} = 2\sqrt{K}T^{\alpha\beta} \tag{3}$$

with retarded potential solutions of the form

$$\phi^{uv}(x) = (\sqrt{K}/2\pi\int T^{uv}(x^{\ell}, x^0) \tag{4}$$

This form will enable the definition of the energy-momentum complex of the gravitational field in order to evaluate the radiation energy and directivity of the gravitational wave.

The Poynting vector of the gravitational wave can be expressed as

$$U_o^l = \frac{1}{8}(-2\phi^{\rho\sigma,l}\phi_{\rho\sigma,o} + \phi^{,l}\phi_{,o}) \tag{5}$$

The derivatives of the potential fields ϕ with respect to time and space coordinates are expressed by the second and third derivatives of the mass tensor,

$$mc^2 \equiv \iiint T^{00}(x', x_G^0)d^3x' \tag{6}$$

momentum tensor,

$$cP^K = \delta_0 x^{K'} \iiint T^{00}(x', x_G^0) d^3x' \qquad (7)$$

and the quadruple moment tensor,

$$I^{iK} = x^i x^{K'} \iiint T_{00}(x', x_G^0) d^3x' \qquad (8)$$

The derivative forms for the potential fields are substituted into the expression for the Poynting vector, thus giving the expression for the radiated energy per unit time, or power, within a solid angle dΩ, as follows

$$P_o^\ell = U_o^\ell d\sigma_\ell = \frac{1}{8}\left(\frac{\sqrt{K}}{4\pi}\right)^2 f(\theta, \phi, x_G^o) d\Omega \qquad (9)$$

Here the factor

$$f(\theta, \phi, x_G^o) \qquad (10)$$

represents the directivity of the gravitational wave radiator.

Of particular interest for this paper is the resonance vibrator, conceptually similar to what Weber[2,3,4] used as a gravitational wave detector. The resonance vibrator is a cylinder (Figure 1), which is placed under stress and strain.

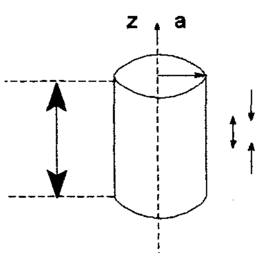

Figure 1: Resonant Vibrator Cylinder

At this point assume the following dynamic variables:

$$\text{Displacement } \varepsilon = A_1 \sin(\frac{\omega}{V_s}) \cos wt \qquad (11a)$$

$$\text{Particle velocity } v = \frac{d\xi}{dt} = -V_p \sin(\frac{\omega}{V_s}) z \sin \omega t \qquad (11b)$$

$$\text{Strain } \varepsilon == \frac{d\xi}{dz} = \frac{V_p}{V_s} \cos(\frac{\omega}{V_s}) z \cos wt \qquad (11c)$$

$$V_p = A_1 \omega \qquad V_2 = (\frac{B_s}{\rho})^{\frac{1}{2}} \qquad (11d)$$

$B_s \rightarrow$ Young's Modulus

The directivity can now be expressed as follows (Figure 2).

$$f \sim \sin^4 \theta \qquad (12)$$

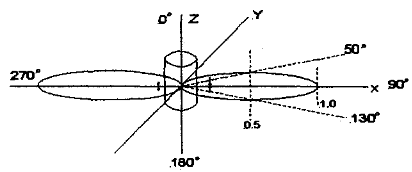

Figure 2: Resonant Vibrator/Gravitational Wave Radiation

The pattern resembles a torus or "donut" mode.

It can be seen that the maximum radiation occurs in the plane perpendicular to the vibrating z axis (Figure 2).

Consider a linear array of resonant vibrators (Figure 3).

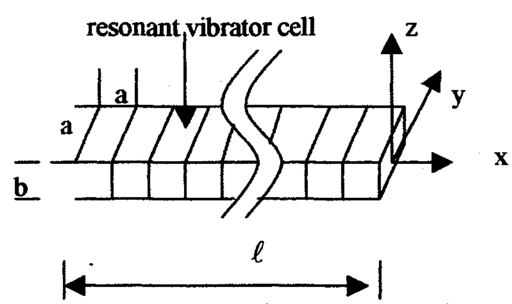

Figure 3: Resonant Vibrator Linear Array

Let high peak power laser radiation from laser diodes be injected along the z axis to induce acoustic stress in the material (Figure 4).

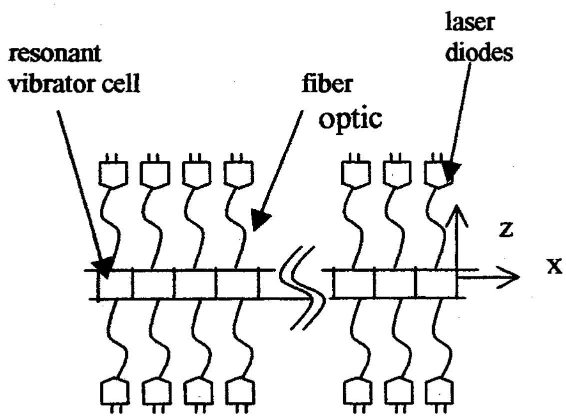

Figure 4: Laser Diodes and Linear Array

The stresses will generate a weak gravitational wave along the x axis. The gravitational wave generated from a number of "cells" along the x axis can be added in phase. The resultant gravitational "beam" along the x axis is extremely intensified compared to a single resonant vibrator "cell." The linear arrangement will be referred to as a traveling wave (TW)gravitational wave (GW) radiator, or TWGW radiator.

The directivity of the TWGW radiator can be expressed as (Figure 5).

$$f \approx \left(\frac{\sin\left(\frac{\pi\omega}{V_s}(1-\cos\Theta)\right)}{\left(\frac{\pi\omega}{V_s}\right)(1-\cos\Theta)}\right)^2 \cos^4\Theta \qquad (13)$$

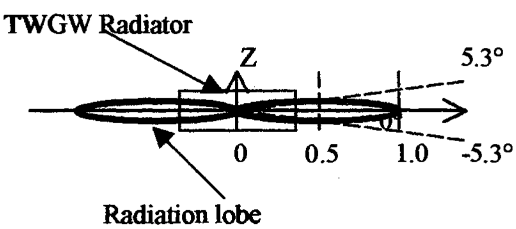

Figure 5: TWGW Radiator Symmetric Radiation Pattern

The graphical result of Figure 5 is based on the geometry of Figure 3 and the constants as follows.

Material: Quartz

$b = 3x10^{-5} m$

$a = 3x10^{-3} m$

$\ell = 0.3m$

$\omega = 6.28x10^{12}$ *radian* / sec

(*resonant frequency*)

$V_S = 5x10^3 m/\sec$ (*wave speed*)

$\rho_o = 2650 kg/m^3$ (*density*)

As can be seen in Figure 5, the TWGW radiation is very directional. This brings to question what type of power levels could be estimated. To begin, consider the single resonant vibrator cell (Figures 2 and 3). The radiated power can be estimated by the following expression.

$$P_{RV} = (5.7x10^{-2}) G \rho_o^2 \pi^2 a^4 e_m^2 V_s \left(\frac{V_s}{C}\right)^5 \qquad (14)$$

Where

$$G = 6.67x10^{-11} \frac{Nt \cdot m^2}{kg}$$

(Gravitational Constant)

$$\varepsilon_M = 4x10^{-3} \text{ (Strain)}$$

Then

$$P_{RV} = 2.14x10^{-29} watt \qquad (15)$$

As anticipated, this is a very small number. However, for the TWGW radiator, the radiated power can be estimated by the following expression.

$$P_{TW} = (7x10^{-5}) G \rho_o^2 a^2 \ell^2 e_m^2 V_s \left(\frac{V_s}{C}\right)^5 \left(\frac{b\omega}{V_s}\right)^6 \Omega \text{ W} \qquad (16)$$

here

$$\Omega(\pm 5.3^\circ) = 2.7x10^{-2} sr$$

(Solid angle of the radiation)

Then

$$P_{TW} = 1.66x10^3 watt \qquad (17)$$

This shows how important the phase relationships between individual resonant vibrators are!

At this point it is important to realize that the radiated gravitational wave carries energy and momentum with it. This is expressed as

$$P = \frac{\varepsilon}{C} = \frac{\underline{P}t}{C} \tag{18}$$

Where $\underline{P}$ is the radiated power, t is time, ε is the energy of the gravitational wave, and P is the momentum.

The resulting reaction force on the TWGW structure is expressed as

$$F = \frac{P}{t} = \frac{\underline{P}}{C} \tag{19}$$

Referring to Figure 5, it can be seen that the radiation pattern is symmetric about the center of the TWGW structure. Therefore any reaction force is balanced! However, consider a variation in the phasing of the laser diodes (Figure 4), where the lobes become asymmetric (Figure 6).

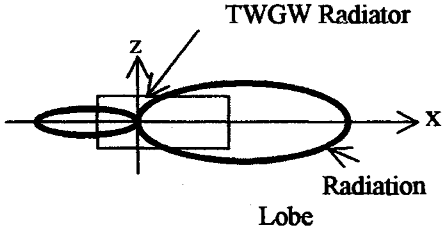

Figure 6: TWGW Radiator Asymmetric Radiation Pattern

This can be accomplished by pulse timing, variation in pulse rate, laser diode intensity, alternate materials, and geometry. Here there is a net force in the direction of the least intense gravitational wave (Figure 7).

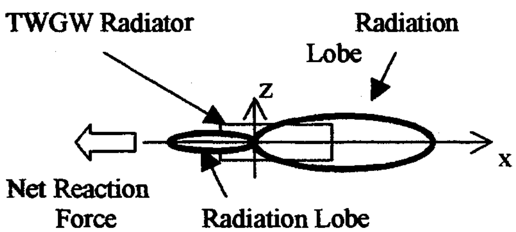

Figure 7: Reaction Force for Asymmetric Radiator TWGW

The reaction force is expressed as

$$\begin{aligned} F_{net} &= F_{RL1} - F_{RL2} \\ &= \frac{\underline{P}_{RL1} - \underline{P}_{RL2}}{C} \end{aligned} \tag{20}$$

As an example, let $\underline{P}_{RL1} = 500$ watt and $\underline{P}_{RL2} = 3.5 \times 10^3$ watt, then

The net force, although small, raises the possibility of a propellantless propulsion concept, utilizing current technologies.

$$F_{net} = 10 x 10^{-6} Nt \tag{21}$$

Further Investigations

Mathematical analysis indicates that gravitational wave propulsion is possible. Further investigation will entail the following objectives.

1) Investigate the efficiency of converting laser light into acoustic stress within TWGW generating material candidates. The acoustic stresses are responsible for generating the quadrapole moment needed to give rise to TWGW radiation. It will be imperative to address questions on how material uniformity, temperature, geometry, laser pulse width, repetition rate, and wavelength will impact performance.

2) Investigate phasing techniques of the TWGW elements in order to create various asymmetries in the radiating pattern. The directivity and intensity of the TWGW radiator is key to the success of generating a net propulsive force. How energy and momentum transports are affected by individual radiator phasing are of utmost importance. The question of whether harmonics distribute energy into other "modes" or are negligible must be considered.

The TWGW system must be analytically modeled as part of the above investigations. The results will lead to study of a test article that will be used to demonstrate the use of the gravitational wave Poynting vector imbalance as a means of generating a propulsive force through the center of mass of the TWGW system. Conceptually a scale version of the system could provide propellantless propulsion into the outer regions of the solar system and/or orbital transfer missions.

Space Flight Application

An interesting example is a comparison of the TWGW system to that of a solar sail at the earth orbital plane. Let the TWGW system be 1000 meters in length. The resulting net propulsive force would be about 61 Nt. For a square solar sail with a perfect reflectivity experiencing a solar flux of 1.3×10^3 watts/m^2, the required area would be around 1.4×10^7 m^2 for a force of 61 Nt. This is a perimeter length of approximately 3.7×10^3m and must be normal to the solar disk to experience the maximum momentum transfer. Also, as the sail increases its distance from the solar disk, the intercepted flux decreases with the square of the distance. The TWGW system is not dependent on the solar disk for operation.

Conclusion

An analytical model has been created to investigate the nature of the radiated TWGW pattern with respect to phase relationships between individual "cell" radiators. Future models will investigate the magnitude of side lobes or harmonics to determine whether asymmetries cause less than desirable effects. These results will be used for evaluation of the generation of a net propulsive force.

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Fabrication of Large Bulk Ceramic Superconductor Disks for Gravity Modification Experiments and Performance of YBCO Disks Under e.m. Field Excitation

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ABSTRACT

We have previously reported on investigations pertaining to the measurements of gravitational field changes in the vicinity of a large rotating Type II superconducting disk. Published reports indicate that test masses have been observed to lose up to 2% of their weight when in the vicinity of such rotating disks. We have produced 30 cm (nominal) diameter disks using $YBa_2Cu_3O_{7-x}$ and BiSCCO. In addition we have performed tests on the interactions between smaller YBCO disks and AC levitation fields and RF fields, using a sensitive gravimeter to monitor and record the local gravity field above the superconductors. We have not yet duplicated the reported experimental protocols, including rotation and levitation of a large two-layered YBCO disk. Static disk experiments to date have uncovered no measurable and repeatable gravity effect for the conditions tested to within the sensitivity of the gravimeter (which has a noise level on the order of 10 nano-G or less).

FABRICATION OF LARGE BULK CERAMIC SUPERCONDUCTOR DISKS FOR GRAVITY MODIFICATION EXPERIMENTS AND PERFORMANCE OF YBCO DISKS UNDER EM FIELD EXCITATION

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Background

Attempts to unify theories of gravity with the other forces of nature have a long and checkered history. Some of the greatest minds the world of physics has known have believed that the connection is there. Clearly at the astronomical scale, gravity and electromagnetics interact through the mechanism of gravitational warping of space around massive bodies. Nonetheless, all credible attempts to experimentally demonstrate that connection on a laboratory scale have remained elusive. It is clear that if a manipulative method is found to treat gravity, extensive changes would occur in our everyday life, just as our lives changed once electromagnetism was understood.

In 1992, E. Podkletnov and researchers at the University of Tampere, Finland, reported [1] demonstration of what he termed "gravity shielding." The experiment consisted of spinning a Type 2 superconductor (yttrium, barium, copper oxide, YBCO) in the presence of electromagnetic levitation and rotation fields and measuring weight changes in test masses suspended above the spinning disk. The effect reported was small, varying from tenths of a percent to as much as 2% of the test mass' weight. A subsequent paper was distributed giving more details of the experiment. [2]

While this is a small effect, it can be recalled that some of the most telling and seminal experiments in electromagnetics in the early 19th century were similarly of small magnitude. Their value was in demonstrating the basic phenomenon; useful amplifications and extensions came from others, once the basic idea had been demonstrated and accepted.

In 1997 researchers at the Marshall Space Flight Center, Huntsville, Alabama, and colleagues began to investigate the Podkletnov experiment. The goal was to understand various phenomena related to the experiment and to replicate it. Marshall has a historical connection to the YBCO material, having been intimately involved in the first fabrication and characterization experiments over a decade ago.

While there is general information available about to experimental set up, several critical details are unclear. However, as we have reported, [3,4,5] progress is being made and our understanding of bulk ceramic superconductors and their interactions with various electromagnetic fields grows. Also, a significant step forward in the measurement of small changes in gravity fields was made with the application of a highly sensitive and stable gravimeter to the experiment. This gravimeter is capable of measuring changes in the local gravity field as small as 5×10^{-9} G. In this paper we will discuss our progress in fabricating large bulk superconductors and various preliminary experiments to understand how these materials interact with AC fields levitation.

Large Bulk YBCO and BiSCCO Disks

The central component in the Podkletnov experiments is a composite structure annular disk of YBCO superconductor. The YBCO material normally exhibits a superconducting transition temperature of around 94K, making it an exciting superconducting material since it is useable with liquid nitrogen cooling. Podkletnov fabricated a dual layered disk, having one layer of YBCO that became superconducting around 94K and another layer that became superconducting around 60K. It is his belief that this composite structure is a mandatory feature to see the effect. Our results to date do not dispute that assertion.

While the ceramic superconductors offer much potential, their well-known characteristics have led present day research with YBCO from bulk to thin film configurations. There are no published reports of fabrication of large bulk ceramic superconductors, in part due to the enormous challenges facing anyone who attempts to fabricate them. Since it is central to our goals, we undertook to fabricate such a disk. Working with colleagues at the University of Alabama in Huntsville and at Martin Technologies, Inc. (also of Huntsville), and after much trial and error, we succeeded in fabricating several single layer YBCO disks (on the order of 30 cm in diameter and ranging in thickness from 0.5 to 1 cm). Recently with our colleagues at Tomorrowtools, Huntsville, we fabricated as 32 cm diameter annular disk made from BiSCCO (bismuth, strontium, calcium, copper, oxide) superconducting material with a nominal superconducting transition temperature between 100 and 110 K. Figure 1 shows the YBCO disk (left) and the BiSCCO disk (right) fabricated at Marshall.

Successful fabrication of such large superconductors resulted from attention to 3 process steps, material selection, mechanical pressing, and thermal processing. Details of the process are being reviewed for patent applicability and so cannot yet be discussed. However, the process results in disks having excellent mechanical structure and moderate superconductive performance as expected from sintered bulk materials. Characterization of the resulting disks indicates transition temperatures for YBCO in the 92K to 94K range and critical currents on the order of 20 to 100 amps/cm^2. The BiSCCO disk is presently undergoing characterization and results are not available.

Fabrication of the YBCO disk used pre-processed YBCO superconducting powders; The process used for the BiSCCO disk was based upon the sol-gel process prepared with precurser nitrates in an autoignition process. Subsequent pressing and heat treating created the correct BiSCCO superconducting formulation.

Only one em field test was run using these large disks, as we are presently completing their characterization. This test involved a preliminary attempt to induce radio frequency energy into the disk and measure any resultant gravity field changes. This test is reported below. Other experiments have been underway using smaller, commercially available YBCO disks to characterize their interactions with various electromagnetic fields. These experiments are also reported below.

Small Disk Interactions with AC Levitation Fields

One series of tests was run to determine how the superconductors react to alternating current, AC, levitation fields. It is generally known that these materials react differently to AC fields than DC. And, again, while much information is available for thin films and very small bulk samples, we believe these tests are the first reported for large pieces.

The experiments were performed using two commercially available melt-textured crystal seeded YBCO disks. One was a single layer disk having a diameter of about 13 cm and a thickness of about 1 cm. The other disk was a 10 cm diameter two layer disk. The levitation field was generated by a 3 solenoid assembly driven by Elgar model 1001SL variable voltage, variable frequency power supplies with a Model 9023 variable frequency oscillator for frequency control. These supplies are capable of generating up to 30 amps from 50 Hz to 4500Hz. Magnetic field characteristics were measured using an F.W. Bell model 9500 gaussmeter. The experimental protocol was to cool the superconductor, place it over the solenoids and turn on the field.

Results show that the 13 cm diameter single layered disk levitated with an 860g field at 45 Hz, 750g at 300 Hz, and 650g at 600 Hz. Levitation was not achieved at higher frequencies due to the inductive reactance of the solenoids and the subsequent current limitations in them. Another test revealed that the 10 cm two-layer disk levitated with 600 g at 45 Hz.

Given these data and the fact that a sintered 30 cm disk will be both heavier and have lower critical current than the melt textured disks above, we expect significantly stronger fields will be required to levitate the large disks. On the other hand, the coils had small field cross sections Larger field cross sections as well as stronger fields will assist levitation.

For one series of tests, we placed the levitating disk approximately 1 meter below the gravimeter. The disk and levitation fields were in a Faraday cage with the gravimeter above and outside the cage. Tests without the disk in place demonstrated that the gravimeter reading was not influenced by the levitation fields. For this test a 45 Hz field was applied to the disk using the 3-solenoid system described above for levitation while the gravimeter was recording. Figure 2 gives the results for one run using the 10 cm two layered disk. Each division on the vertical scale is 10 nano-G; each division on the horizontal scale is 72 seconds in elapsed time. In all cases reported here, the gravimeter is set for a 2 second sample integration time. The results of this test show no evidence of any effect of the levitating disk on the gravimeter above the noise level of the gravimeter. Other frequencies were run with similar results. At higher frequencies, fields were applied even though they were insufficient to levitate the disk. In some cases changes in the gravity reading are seen; however, they are all on the order of a 100 nano-Gs or less and are not repeatable.

Figure 3 (having the same scale as Figure 2) exhibits data from a run in which the 10 cm composite structure disk was exposed to 9 pulses of 45 Hz field. For this test field intensity was 1100 gauss and the disk did levitate with each pulse. Pulse rate was one pulse per minute with a 50% duty cycle. As can be seen, there is no significant change visible the in gravimeter reading during the experiment although there are minor transients that may be related to the pulses. The experimental setup was as described above.

It has been suggested that when a superconductor transitions from normal to super conducting mode, a possible transient gravity signal is produced. Figure 4 exhibits data from a run in which gravimeter readings were taken during cooldown of the 2 layer disk using the experimental setup described above. The figure shows where the liquid nitrogen was first poured and when rapid boiling of the liquid stopped. A small magnet levitated when placed over the disk at the cessation of boiling, indicating that the disk was superconducting.

In summary, no conditions were found in which excitation of a small YBCO disk by a low frequency levitation signal produced repeatable changes in the gravimeter reading.

Large YBCO disk RF Field Interactions

A series of experiments was run to characterize the effects of megahertz-range rf on a 30 cm YBCO disk. The experiments used a tunable rf generator and amplifier capable of 100 watts output between 1 and 100 MHz. Most tests focused on the 3 to 20 MHz range. Rf was applied through a 12 turn coil wound toroidally around one section of the disk. An impedance matching network was used to maintain a constant load to the amplifier.

Initial tests demonstrated that the gravimeter was susceptible to the rf. This susceptibility manifested itself in lockup of the gravimeter data system at high rf levels (25 watts or more). This susceptibility was eliminated using standard rf shielding procedures on the gravimeter and by enclosing the YBCO disk and rf coil in a grounded Faraday cage.

Figure 5 is representative of these tests. In this case a series of four 3.5 MHz, 100 watt pulses were applied to the disk while it was superconducting. As can be seen, there are changes in the gravimeter reading appearing to coincide with the pulses, having amplitudes on the order of 10 nano-G.

Other tests performed include application of rf during cooldown of the disk and measurement of the gravity field with various rf frequencies applied. These data are presently being evaluated and will be reported later. In general, there are more repeatable and consistent gravimeter variations observed with the rf excitation than with the low frequency AC levitation excitation. However, all changes seen to date are less than 100 nano-G in amplitude.

Summary

We have succeeded in manufacturing large (30 cm diameter) superconducting disks using the YBCO and BiSCCO materials. These disks, weighing between 3 and 4 Kg, depending on thickness, are being used to investigate reported interactions between em fields and the local gravity field.

The reported interactions occur in an experimental protocol that we have not yet duplicated. Our initial attempts are to individually characterize possible interactions under static (non-rotating) conditions. We have completed these initial characterizations, data is being analyzed, and preliminary results were reported here.

All observed interactions were on the order of nano-Gs and considerable care is being taken to assure that these observations are not artifacts of the experimental set up or interactions between the em fields and the gravimeter.

We are currently developing experimental hardware to test the large disks now being routinely fabricated. We expect to achieve levitation of the 30 cm disks under em field excitation later this year, with rotation soon to follow. Further experiments are also underway to optimize disk fabrication for increased critical current and mechanical stability and to develop a process to fabricate a two layered 30 cm disk.

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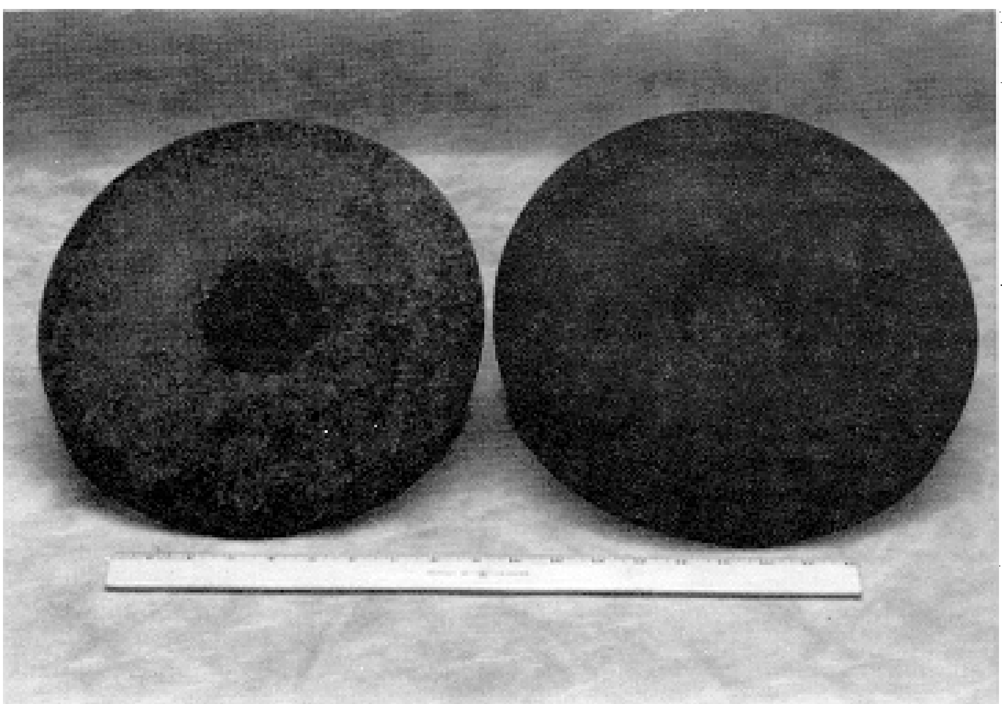

Figure 1 30 cm YBCO superconducting disk (left) and 32 cm BiSCCO superconducting disk (right) fabricated at NASA/MSFC.

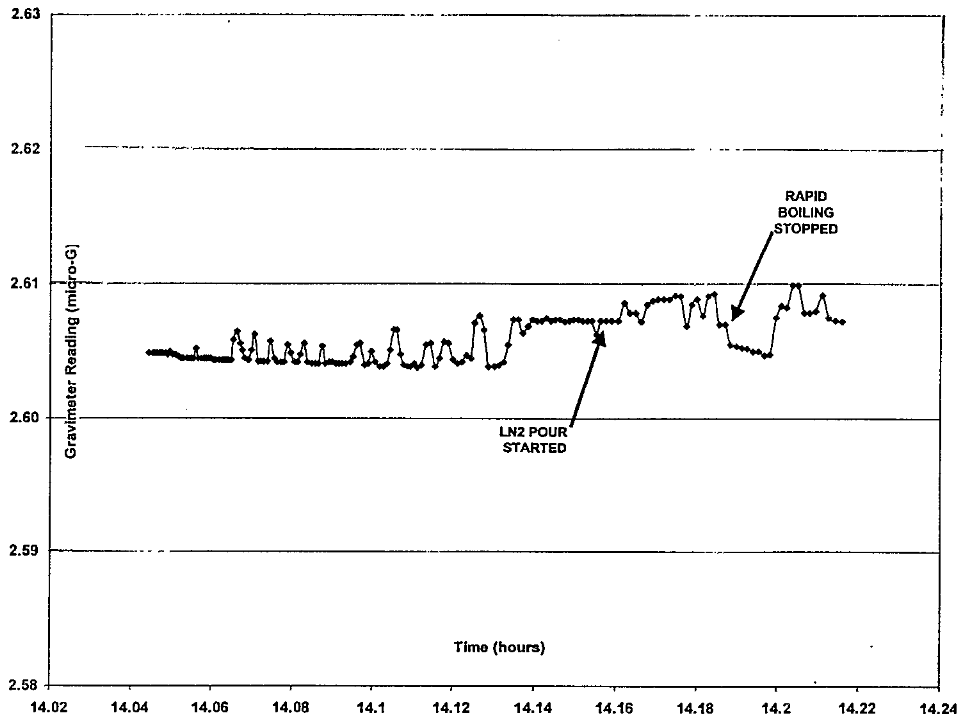

Figure 4 Gravimeter reading during cool down of a 10 cm YBCO superconducting disk.

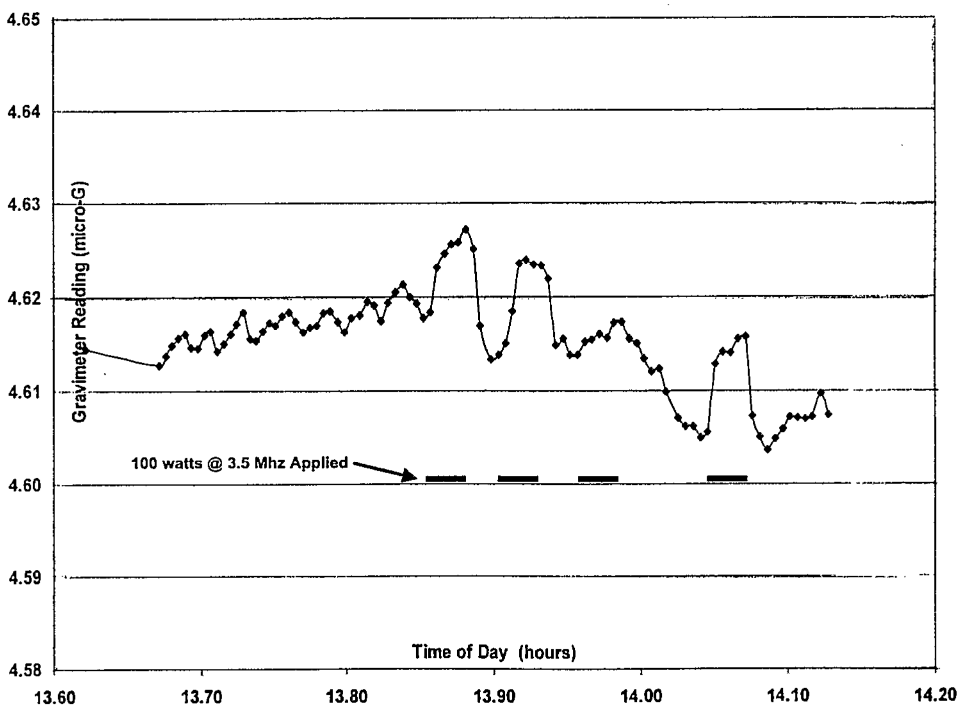

Figure 5 Gravimeter reading during rf excitation of a 30 cm YBCO superconducting disk.

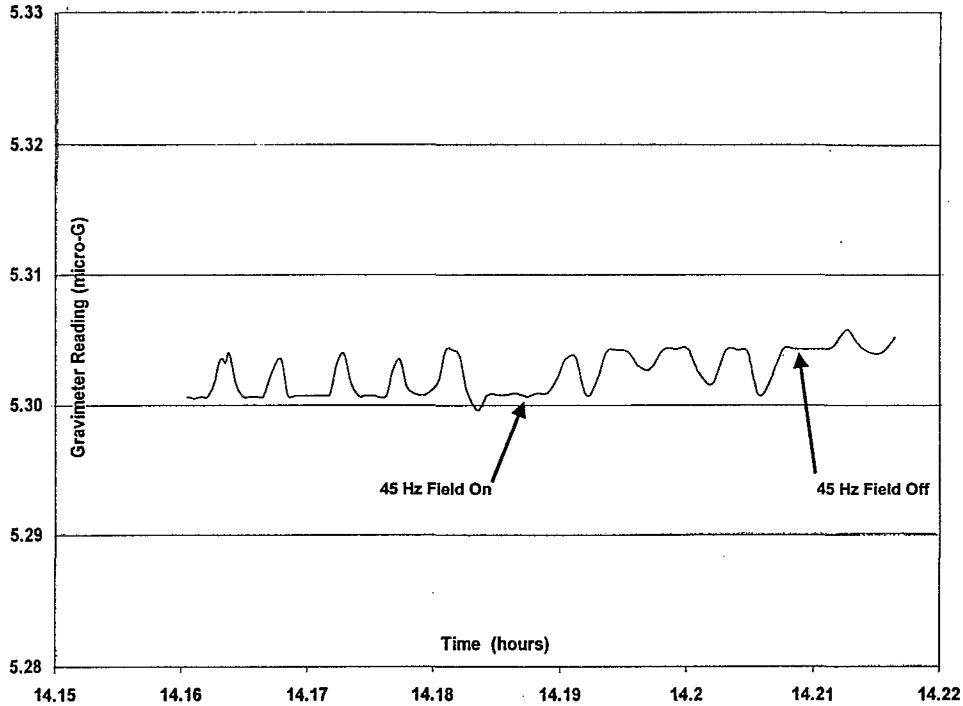

Figure 2 Gravimeter reading with 600 gauss, 45 Hz levitation field applied to a 10 cm YBCO superconducting disk.

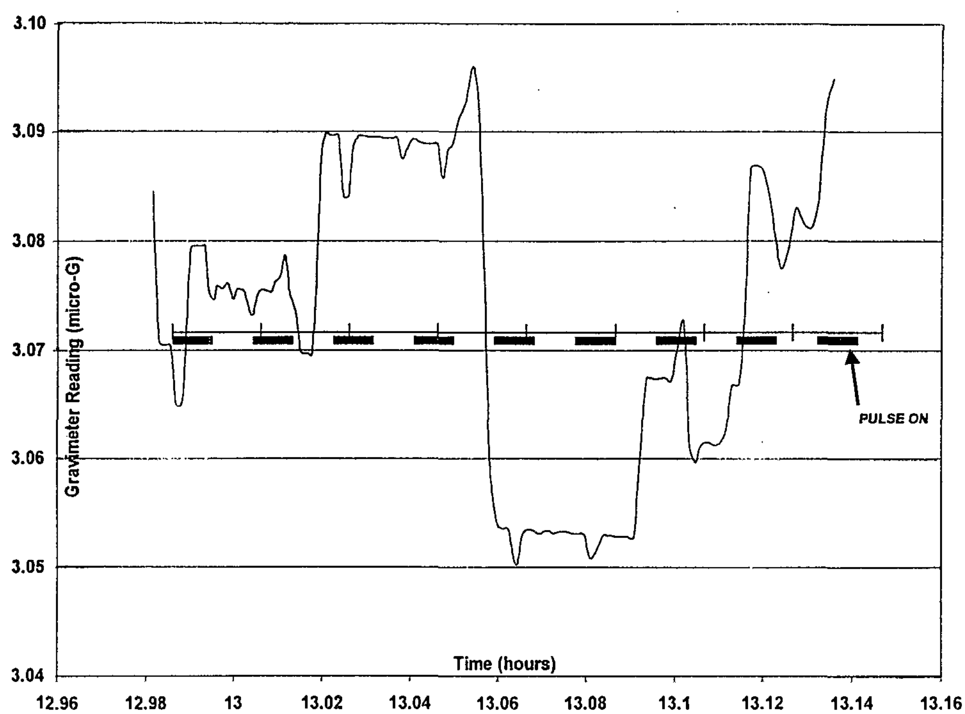

Figure 3 Gravimeter reading with 9 pulses of 1100 gauss, 45 Hz levitation field applied to 10 cm YBCO superconducting disk.

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Large Scale Sakharov Condition

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ABSTRACT

Recent far-reaching theoretical results have used the quantum vacuum noise as a fundamental electromagnetic radiation field to derive a frequency (ω) -dependent version of Newton's gravitational coupling term, $G(\omega)$. This paper reconciles the cutoff frequency with the observed cosmological constant, then briefly puts forward a realizable laboratory test case in the 10-100 MHz frequency range. One analogy is drawn between the classical vacuum energy experiments with attraction between two closely spaced plates (Casimir cavity) and the arbitrarily dense material boundaries possible in Bose condensates, such as irradiation at MHz frequencies of superfluid helium or superconductors.

LARGE-SCALE SAKHAROV CONDITION

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Theoretical Background

Zel'dovich [1] first suggested that gravitational interactions could lead to a small disturbance in the (non-zero) quantum fluctuations of the vacuum and thus give rise to a finite value of Einstein's cosmological constant in agreement with astrophysical data. Using dimensional analysis and the suggestion by Zel'dovich, Sakharov [2] derived a value for Newton's gravitational constant, G, in only one free parameter, frequency, ω:

$$G \sim c^5/h \int \omega \, d\omega \sim 1/\int \omega \, d\omega$$

where c is the speed of light and h is the Planck constant. The free parameter in frequency when integrated over all values from zero to high frequencies, must contain the usual integration cutoff value (Planck frequency on observable electromagnetic phenomenon).

Puthoff [3] and others [4-5] have extended Sakharov's condition in a relativistically consistent model to determine constants of proportionality. His model derives an acceleration term in first order expansion (in flat space-time), then equates inertial and gravitational mass (by the equivalence principle) to make contact with the gravitational constant, G, directly as:

$$G = (\pi c^5/h\omega_c^2) \sim 1/\int \omega \, d\omega$$

which is the Sakharov condition [2,3]. This paper revisits the meaning of the cutoff frequency, ω_c, for radiation interactions, of which the quantum vacuum [6-10] and Planck frequency are only the leading terms, and for which linear combinations of forces can introduce other plausible frequencies. One purpose of this reexamination is whether the resulting gravitational coupling constant, G, can be reconciled with the anticipated energy density of the universe [11] without resorting to extreme space-time curvature and thus yield enough critical density to contain the expansion of the universe. Finally we particularize the case to the high density fluctuations possible in Bose condensates [12], a potential experimental test case for how the effects of vacuum noise might manifest observably.

One far-reaching consequence of the vacuum energy model is the attractive force of gravity becomes reducible to the radiative interaction between oscillating charges, e.g. the zero point field (ZPF) applied to subatomic charges. Mass and inertia arise from the fundamentally electromagnetic ZPF oscillations.

This random background gives the usual quantum mechanical energy spectrum from particle-field effects:

$\rho(\omega)\, d\omega \sim \omega^3\, d\omega$,

a very important dimensional relationship, since the third power in frequency avoids anomalous Doppler shifts from velocity boosts, or stated alternatively is the correct spectra for a Lorentzian (non-accelerated) invariant radiation field [13].

More specifically, the energy spectrum [3] can be written as:

$\rho(\omega)\, d\omega = [\omega^2/\pi^2 c^3]\, [h\omega/2] d\omega$
$= h\omega^3/2\pi^2 c^3\, d\omega \sim \omega^3\, d\omega$

which is an expression in the first parenthesis of the density of the normal modes and in the second parenthesis of the average energy per mode. When this energy density is integrated over all frequencies, the ω^3 divergence produces well-known infinities in the integration limit of high frequencies, thus an assumed cutoff frequency (appropriate to experimental observation limits at the Planck frequency), is usually introduced:

$\omega_p = (c^5/hG)^{1/2}$

For mass, m, moving in an accelerated reference frame, $g = -a = Gm/r^2$, the resulting energy spectrum includes a gravitational spectral shift [3],

$\Delta\rho'(\omega)\, d\omega = h\omega/2\pi^2 c^5\, [Gm/r^2]^2 d\omega \sim 1/r^4\, d\omega$

a kind of short-range ($1/r^4$) gravitational energy shift, but electromagnetic in origin when zero point fluctuations are included. (N.B. To account for equal gravitational mass effects in neutrons and protons, the ZPF oscillations must involve subatomic charges, or 'parton' effects. The assumption derives from high-frequency interactions of ZPF wherein these subatomic particles are asymptotically free to oscillate as independent or free particles as quantum noise].

A further far-reaching consequence [3] is mass itself becomes interpretable as a dependent quantity derived from a damped (with decay constant, Γ) oscillation driven by random ZPF:

$m = \Gamma c^3/G = 2h\, \Gamma/\pi^2 c^3 \int \omega\, d\omega$,

with the only two free parameters, the damping factor Γ, and again the frequency, ω. The internal kinetic energy of the system contributes to the effective mass.

This leads to an overall average spectral density, written in terms of mass as:

$\Delta\rho'(\omega) = m^2 c^5 \omega / 2h\omega_c^4 r^4$

for the electromagnetic field distribution near ($1/r^4$) to the mass, m, which in detail is half electric and half magnetic.

One additionally attractive feature is the correspondence between this derivation and the view of gravity as a dynamical scale-invariance-breaking model (e..g symmetry breaking near the Planck mass energy [14]). A final result includes the force calculation between two ZPF radiation oscillators, of the correct form yielding Newton's average force law:

$\langle F \rangle = -Gm^2/r^2$

Thus, for a Newtonian force to first order in a flat space-time, Sakharov [2] could be credited for proposing gravity as not a fundamentally separate force and Puthoff [3] and co-workers [4-5] applied the vacuum electromagnetic field to equate gravity to a long-range radiation force (e.g. van der Waals-like force). Higher order oscillatory gravity modes vary as $(\sin[\omega_o/\omega_c])^2$.

To first order, a weak G coupling constant, $G = (\pi c^5/h\omega_c^2)$, appears for high frequency cutoffs at the Planck scale. A corollary in analogy to electromagnetic shielding by ordinary matter can be rationalized as the problem of frequency mismatch at high Planck frequencies, e.g. ZPF cannot be fundamentally shielded. In other words, frequency mismatch precludes gravity shielding by matter.

The purpose here is to revisit the only free parameter, the frequency cutoff, more in the spirit of a mass resonant frequency. The motivation for this approach can be summarized as: 1) the generality of other complementary radiation effects without relying on ZPF alone (e.g. other isotropic, homogeneous radiation sources); 2) the weak coupling constant, G, yields a vastly smaller than observed size of the universe (e.g. too small cosmological constant) when the Planck frequency is used as a cutoff value; and (3) the particle mass, $m = \Gamma c^3/G$, can be viewed as a renormalized or 'dressed' mass with a resonant interaction potential that is frequency dependent in its coupling constant, G, and with 'bare' mass that is large, $m_o \sim (m_p^2/m)$, where the experimentally unobservable, $m_p = (hc/G)^{1/2}$ is the Planck mass.

In particular, why this large 'bare' mass does not generate a large gravitational field is not a unique anomaly in the Sakharov derivation, since similarly large vacuum point energies are common to field theories. The important point is that the derivation $G(\omega)$ is general however to any isotropic radition field with the Lorentz-invariant energy spectra [$\rho(\omega) \sim\omega^3$], thus the candidates for the cutoff frequency of the particular radiation source can be interpreted as a Planck scale only if the rest mass, m_o, is not composed of many terms, rather than just the ZPF leading term. Since the ZPF is akin to a van der Waals force [3-5], polarizability (in charge and mass) must be considered, but without also excluding any number of linear combinations that might have alternative cutoff frequencies, ω_c, or damping terms, Γ, 'ala particle physics interpretations for resonant masses during renormalization. In other words, once a gravitational energy spectrum, $\rho(\omega)$, is postulated that is Lorentzian invariant, many fundamental sizes (or corresponding frequency values) are smeared (or dressed) by any number of characteristic frequencies between zero and the high frequency electromagnetic (Planck) cutoff, ω_p. Quite simply, is the expression, $\omega_c = \omega_P$, a requirement for all radiation sources?

Many types of particle oscillations may satisfy the general requirements of a Sakharov condition, each having a characteristic mass (and energy) as in calculating the mass of any fundamental particle at its resonant frequency (including underlying partial charges or dense bosons). This brings the calculation to a consideration of the high density fluctuations characteristic of a Bose condensate [15-19]. While the high density variation may intrinsically be of interest, the exploration has more to do with reconciling the ZPF interpretation of the Sakharov condition with the observed cosmological constant [14].

A 'top-down' view of calculating the cutoff frequency imposes the self-consistency test for the cosmological constant, Λ, from the outset. To calculate, Λ, for ZPF, the total frequency-integrated energy density of the universe must be included:

$$\rho(E)=\int \rho(E)\, dE = h\omega_c^4/8\pi^2c^3$$

which must have a mass equivalent, contribute to the universe's curvature, and thus have a fundamental relation to the critical density to contain the expansion of the universe [14-15]. The mass-equivalent ZPF to reach the universe's critical density [15], $\rho\sim10^{-29}$ g cm^{-3} would necessarily limit the cutoff frequency for gravity to the value, $\omega_c<7\times10^7$ s^{-1}, or between 10-100 MHz.

A higher frequency greatly overshoots the cosmological constant, Λ, and induces extreme curvature in the universe. This problem has been cited frequently and stated most bluntly as either ZPF or the cosmological constant requires revision. The relevance here arises from similarly large positive coupling terms in quantum gravity [15], which also generate a local gravitational instability for typical upper limits on the cosmological constant, $\Lambda/8\pi G<10^{12}$ cm^{-4}.

Rather than to dwell on the inconsistencies that plague attempts to reconcile quantum gravity, we particularize the problem to a case where the restriction to Planck scale becomes less clear, namely the high density fluctuations and universal scaling introduced in a Bose condensate. A Bose condensate, such as superfluid helium or superconductors [15-19], becomes of potential interest, mainly because of its arbitrarily dense boundaries and the classic Casimir experiment [20-22] which allows such dense material boundaries (two closely spaced conducting plates), if available, to modulate the background quantum fluctuation of ZPF. In other words, the matter-ZPF interaction becomes measurable by the observed attraction between two material boundaries. What dense boundaries might generate in Bose condensates remains a subject of greate interest.

The significant case to investigate is whether Casimir-like interactions [20-22] will not only couple to ZPF radiation at a scale comparable to the quantum noise (or other radiation field), but also alter the value imposed by the Sakharov condition for G. It remains an open question whether this potential coupling interaction shares, as in ordinary critical phenomenon, the density correlation function, Φ, that is both independent of the coupling strength (or universal in renormalization) and consistent with the observed average energy density of the visible universe.

Thus the purpose here has been to restate the Sakharov condition in the gravitational coupling constant, G, based on its only free parameter, a frequency cutoff, ω_c. Any potential relevance arises from similarly large values for the positive coupling term in quantum gravity, which generate conditions for a local gravitational instability for typical upper limits on the cosmological constant, $\Lambda/8\pi G<10^{12}$ cm^{-4}.

To restate the Sakharov condition, matter in the vacuum provides boundaries for reduced 'Casimir-like' modes available for otherwise isotropic radiation from quantum fluctuations (broad spectral noise). That this view reproduces Einstein gravity has been examined, including the full relativistic derivation [4-5]. The details of the appropriate mass, however, remain buried in the kinetic energy of general internal particle ('parton') motion [3]. Any appeal to a specific parton representation is limited only by essentially free particles with high-frequency interactions, including underlying partial charges or dense bosons. The basis of considering arbitrarily high density fluctuations in Bose condensate in analogy to the ZPF-Casimir experiment remains both an empirical and theoretical case to examine. There exist laboratory scale cases [15-19] where resonant radiation in the required 10-100 MHz range appear to produce anomalous effects for such Bose condensates as superconductors, but further work to confirm these results would be needed. In other contexts, these effects have been discussed as the Schiff-Barnhill effect for superconductors interacting with a gravitational field [23], but for the static rest mass rather than an effective mass in a conduction band.

Experimental Propositions

J. Weber [24,25] proposed the use of a superconducting Bose condensate for gravity wave detection, principally because of its potentially higher signal-to-noise ratio in carrying electrical signals upon length dilations in a relativistic framework for gravity waves travelling near the speed of light. W. Weber and Hickman [26] derived an experimentally testable relation based on torquing of a charged capacitor parallel to a gravity field, with

$$\tau=2E_g/\pi\,[\alpha/(1-\alpha)^{1/2}],$$

where the capacitor will rotate relative to the gravity vector, for $\alpha=2GM/rc^2$, r is Schwarzschild radial coordinate $[dR=dr(1-\alpha)^{1/2}]$, E_g is dependent on the capacitor charge and geometry of the plates, $E_g=Q^2d/[2\varepsilon WL(1-\alpha)^{1/2}]$, for a plate separation, d, and radial dimensions, W and L, charge Q, and ε the permittivity of free space. For plate separations of 2 mm on Earth, the maximum torque is approximately $\tau=10^{-12}$ Nm, when charged to 2/3 dielectric breakdown. While not entirely promising for detection of such low torques, the large separation (2 mm) distance between capacitative plates naturally prompts generalization to the classic Casimir force [21] experiments only recently confirmed experimentally [20]. In particular, we rewrite the torque values to include the frequency terms derived with the Sakharov condition $[G=(\pi c^5/h\omega_c^2)]$:

$$\alpha=2M\pi c^3/h\omega_c^2 r$$

The appeal of this formulation is that a frequency dependent torque is derived, which further makes contact with proposals to modulate the Casimir capacitative plates for continuous extraction of energy [27]. This result requires further investigation experimentally, particularly to compare with previous reports for anomalies in AC-tuned electrical capacitors [28].

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$\mu_g=4\pi G/c^2=4\pi^2c^3/(h \int_0^{\omega c}\omega d\omega) \sim 1/\int \omega\, d\omega$
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National Aeronautics and
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BREAKTHROUGH PROPULSION PHYSICS RESEARCH PROGRAM

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Abstract

In 1996, a team of government, university and industry researchers proposed a program to seek the ultimate breakthroughs in space transportation: propulsion that requires no propellant mass, propulsion that can approach and, if possible, circumvent light speed, and breakthrough methods of energy production to power such devices. This Breakthrough Propulsion Physics program, managed by Lewis Research Center, is one part of a comprehensive, long range Advanced Space Transportation Plan managed by Marshall Space Flight Center. Because the breakthrough goals are beyond existing science, a main emphasis of this program is to establish metrics and ground rules to produce near-term credible progress toward these incredible possibilities. An introduction to the emerging scientific possibilities from which such solutions can be sought is also presented.

INTRODUCTION

In 1996, Marshall Space Flight Center (MSFC) was tasked to formulate a comprehensive strategic plan for developing space propulsion technology for the next 25 years. This "Advanced Space Transportation Plan" spans the nearer-term launcher technologies all the way through seeking the breakthroughs that could revolutionize space travel and enable interstellar voyages.

New theories and phenomena have emerged in recent scientific literature that have reawakened consideration that such breakthroughs may be achievable. To establish a program to address these visionary possibilities, a "Product Definition Team" of researchers was assembled. This team, led by NASA Lewis Research Center, consisted of 19 individuals from various NASA Centers, other government laboratories, industries, and academia (listed in acknowledgments section). Most team members are part of an existing informal network that had already recognized the potential of the emerging science and had conducted preparatory research on how to apply these prospects to the goal of creating revolutionary propulsion.

To anchor the program in real and tangible terms, the team configured the program to produce near-term, credible, and measurable progress toward determining how and if such breakthroughs can be achieved -- credible progress to incredible possibilities. There is no guarantee that the desired breakthroughs are achievable, but it is possible to produce progress toward a goal without first proving it is achievable. This paper introduces how this program aims to answer these challenges as well as giving a brief introduction to the emerging physics which reawakened interest in these visionary ambitions.

SPECIFYING GOALS AND SCOPE

To focus the program, the first step is to specify what breakthroughs are genuinely required to revolutionize space travel. A NASA precedent for systematically seeking revolutionary capabilities is the "Horizon Mission Methodology" (Anderson 1996). This method forces paradigm shifts beyond extrapolations of existing technologies by using *impossible* hypothetical mission goals to solicit new solutions. By setting impossible goals, the common practice of limiting visions to extrapolations of existing solutions is prevented. The "impossible" goal used in this exercise is to enable practical interstellar travel. Three major barriers exist to practical interstellar travel; propellant mass, trip time, and propulsion energy. To conquer these hurdles the following three propulsion breakthroughs are sought. These are the goals of the Breakthrough Propulsion Physics program:

(1) Eliminate or dramatically reduce the need for rocket propellant. This implies discovering fundamentally new ways to create motion, presumably by manipulating inertia, gravity, or by any other interactions between matter, fields, and spacetime.
(2) Dramatically reduce trip time to make deep space travel practical. This implies discovering a means to move a vehicle at or near the actual maximum speed limit for motion through space or through the motion of spacetime itself. If possible, this means circumventing the light speed limit.
(3) Discover fundamentally new on-board energy production methods to power propulsion devices. This third goal is included in the program since the first two breakthroughs could require breakthroughs in energy generation to power them, and since the physics underlying the propulsion goals is closely linked to energy physics.

The scope of this program only covers seeking the genuinely needed breakthroughs rather than seeking refinements to existing solutions. As such, existing concepts that are based on firmly established science, such as light sails, magnetic sails, beamed energy, nuclear rockets, and antimatter rockets, are not part of this program. These concepts are being explored in other programs.

SCIENTIFIC FOUNDATIONS

New possibilities have emerged in recent scientific literature that have reawakened interest toward conquering the goals described above. These include theories that suggest that gravity and inertia are electromagnetic side effects of vacuum fluctuations (Haisch 1994 and Puthoff 1989), anomalous experimental evidence suggesting a possible gravity altering affect from spinning superconductors (Podkletnov 1992), theories suggesting that faster-than-light transport may be possible using wormholes (Morris 1988) or using warp drives (Alcubierre 1994), and a theory suggesting that sonoluminescence is evidence of extracting virtual photons from vacuum fluctuation energy (Eberlein 1996). These are in addition to older theories about creating propulsive effects without rockets (Bondi 1957 and Forward 1963).

In addition, there have been workshops (Bennett 1995, Evans 1990, and Landis 1990), recent surveys (Cravens 1990, Forward 1990, and Mead 1989), suggested research approaches (Cramer 1994, Forward 1984 and 1996, and Millis 1996), and even some exploratory experiments (Millis 1995, Schlicher 1995, and Talley 1991) on this subject. And recently, a non-profit society, the Interstellar Propulsion Society, was established to provide a collaborative forum to accelerate advancements toward these goals (Hujsak 1995).

PROGRAM CHALLENGES

Since the scientific principles do not yet exist from which to engineer the technological solutions to these challenges, new scientific principles are sought. Seeking such visionary and application-focused physics is not a usual activity for aerospace institutions, so this program faces both the technical challenge of discovering the desired breakthroughs and the programmatic challenges of how to conduct this work. To answer these challenges, the program will develop the research solicitation and selection criteria and the metrics for quantifying progress to meet the technical and programmatic challenges.

The technical challenges include: (1) focusing emerging theories and experiments to answer NASA's propulsion needs, (2) finding the shortest path to developing the breakthroughs amidst several, divergent and competing approaches, and (3) balancing the imagination and vision necessary to point the way to breakthroughs with the credible, systematic rigor necessary to make genuine progress.

The programmatic challenges include: (1) advocating such long range research amidst dwindling resources and stiff competition from nearer-term, more conservative programs, (2) creating confidence that research funded today will lead to the necessary breakthroughs, (3) selecting the most promising research tasks from the large number of divergent and competing approaches, and (4) conducting meaningful and credible research economically.

PROGRAM PRIORITIES

To simultaneously focus emerging sciences toward answering the needs of space travel and to provide a programmatic tool for measuring progress and relevance, this program will develop prioritization criteria suitable for breakthrough-seeking research. These criteria help potential researchers to focus their work, and provide NASA with the means to quantify the relative benefit of competing research proposals. Examples of these criteria, which are still evolving, are presented below:

- APPLICABILITY: Research proposals that directly address a propulsive effect are given preference over those addressing basic science or supporting technologies.
- EMPIRICISM: Research proposals for experimental tests are given preference over proposals for analytical or theoretical work. Empiricism is considered to be a more direct indication of physical phenomena and experimental hardware is considered to be closer to becoming technology than pure theory.
- TARGETED GAIN: Research proposals that address large potential improvements in propulsive abilities are given preference over those of lesser potential improvements. This comparison can only be made between concepts that are of similar developmental maturity. Targeted gains include reducing trip time, reducing non-payload vehicle mass, reducing energy requirements, and reducing development cost.
- ACHIEVABILITY: Research proposals whose subjects are closer to becoming a working device are given preference over longer range developments. This comparison can only be made between concepts that are of similar propulsive ability.
- IMPACT: The more likely the research results will be used by others, the higher it is ranked.

Another criteria to be used is a "Traceability Tree." This tree is the reverse of a fault tree (a common tool used in accident risk assessments). Instead of branching out all the ways that a given accident can occur, the Traceability Tree branches out the conceivable paths to reach a propulsion breakthrough, Figure 1. This tool provides a means to measure how a given research task is linked to the end goals of discovering a propulsion breakthrough.

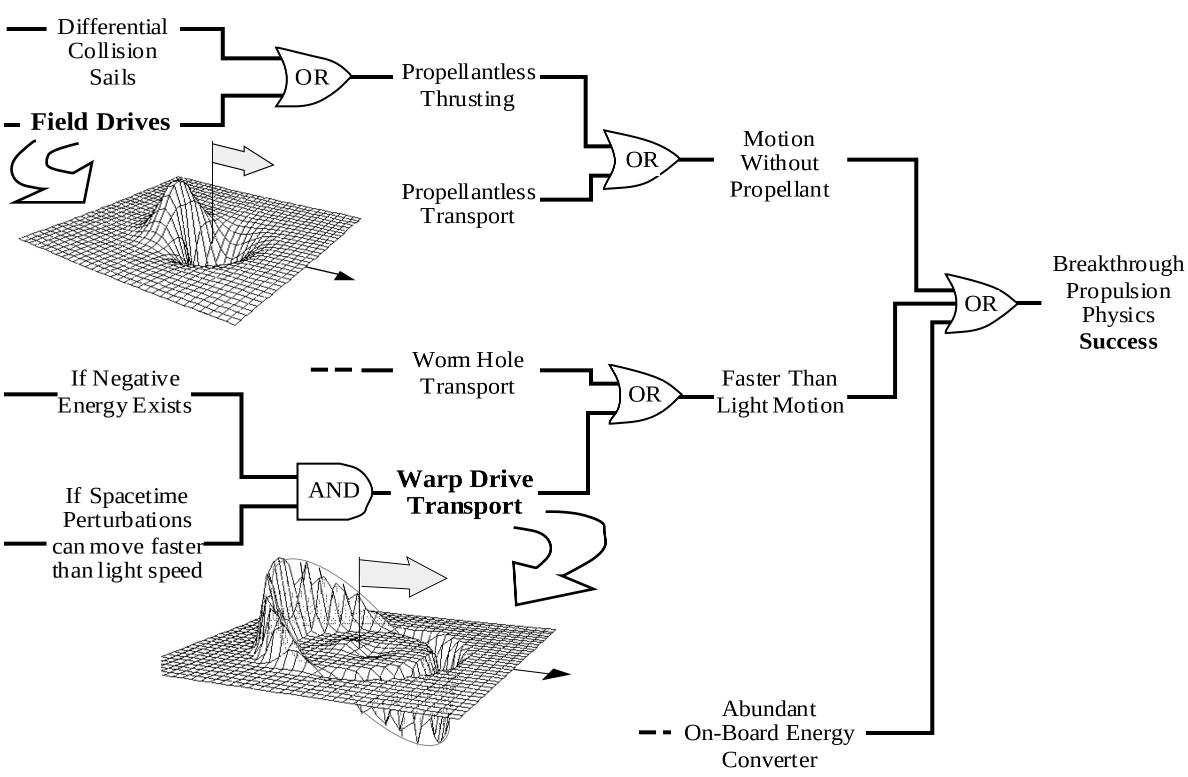

FIGURE 1. Illustrative Example of a Traceability Tree.

Another philosophy behind the NASA program is to support multiple small tasks rather than a single, larger task. Since the search for breakthrough propulsion physics is at an early stage, there are a large number of divergent and competing approaches. It is still too soon to tell which approaches will provide the shortest path to success. To cover the bases, a diverse program of multiple, small, and short-term projects is preferred.

To balance vision and imagination with credible systematic rigor, the NASA program is open to perspectives that go beyond or appear to contradict conventional theory, with the conditions that (1) the perspectives must be completely consistent with credible empirical evidence, (2) the utility of the alternate perspective must be clearly delineated, and (3) the make-or-break issues must be clearly identified to suggest the next-step research objectives.

There is another facet to this "beyond conventionalism." Institutions such as NASA routinely get numerous unsolicited submissions from individuals who claim to have a breakthrough device or theory. Frequently these submissions are too poorly conceived or incomplete, or too complex to be easily evaluated. To distribute this workload to other credible organizations and to keep an open mind to the possibility that one of these maverick inventors may have actually made a breakthrough, the following approach is suggested. Any individual who thinks they have a breakthrough device or theory is strongly advised to collaborate with a university or other educational institute to conduct a credible test of their claim. The university can propose the test as an educational student project, where the students will learn first-hand about the scientific method and how to apply systematic rigor and open-mindedness in conducting a credible test of an incredible claim. In such collaborations it is suggested that the inventors retain full intellectual property rights to their devices or theories, and that the universities make the proposal and receive all the funds to conduct the student projects. With this procedure, if the device or theory works, then supporting evidence would be established in a credible fashion and the originator would retain the intellectual property rights. If the device or theory does not work, then at least the students would have had a meaningful educational experience, and the concept's originator can work on another idea.

MEASURING PROGRESS

One of the challenges to this program is to demonstrate that research conducted today is making measurable progress directly toward the long-range targeted breakthroughs. The traceability tree and selection criteria presented earlier provides a means to demonstrate that a given research approach is linked to the end goals, but another metric is needed to quantify that progress is being made. To provide this measure, a more explicit version of the Scientific Method is used for measuring the level of advancement of a given scientific approach, similar to the way that the "Technology Readiness Levels" (Hord 1985) are used for quantifying technological progress. A draft of these scientific readiness levels is below:

- **Pre-Science**: Suggests a correlation between a desired effect and an existing knowledge base, or reports observations of unexplained anomalous effect.
- **Scientific Method Level 1, Problem Formulation**: Defines a problem specifically enough to identify the established knowledge base and the remaining knowledge gaps. A "problem" is an explicit statement of a desired goal (e.g. the 3 Breakthrough Propulsion Physics program goals) or explicit observations of an anomalous effect which cannot be explained using the established knowledge base.
- **Scientific Method Level 2, Data Collection**: Compiles relevant information to address a specific problem by experiment, observation, or mathematical proof.
- **Scientific Method Level 3, Hypothesis**: Suggests a mathematical representation of an effect or the relation between physical phenomena.
- **Scientific Method Level 4, Test Hypothesis**: Empirically tests a hypothesis by comparison to observable phenomena or by experiment.
- **Technology Readiness Level 1, Basic Principles Observed and Reported**: Equivalent to established science, where an effect has been observed, confirmed, and modeled sufficiently to produce a mathematical description of its operation.
- **Technology Readiness Level 2, Conceptual Application Designed.**
- **Technology Readiness Level 3, Conceptual Design Tested Analytically or Experimentally.**

STATUS AND DIRECTION

A government steering group containing members from various NASA centers, DOD and DOE laboratories has been established to develop the research solicitation and selection criteria to meet the programmatic and technical challenges. These criteria are to be in place by mid 1997, in time for the next program milestone; a kick-off workshop. The invitation-only workshop will examine the relevant emerging physics and will produce a list of next-step research tasks. If the workshop successfully demonstrates that promising and affordable approaches exist, funding may be granted to begin conducting the step-by-step research that may eventually lead to the breakthroughs.

CONCLUSIONS

New theories and laboratory-scale effects have emerged that provide new approaches to seeking propulsion breakthroughs. To align these emerging possibilities toward answering the propulsion needs of NASA, a research program has been established that focuses on producing near term and credible progress that is traceable to the breakthrough goals.

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In 1996, a team of government, university and industry researchers proposed a program to seek the ultimate breakthroughs in space transportation: propulsion that requires no propellant mass, propulsion that can approach and, if possible, circumvent light speed, and breakthrough methods of energy production to power such devices. This Breakthrough Propulsion Physics program, managed by Lewis Research Center, is one part of a compehensive, long range Advanced Space Transportation Plan managed by Marshall Space Flight Center. Because the breakthrough goals are beyond existing science, a main emphasis of this program is to establish metrics and ground rules to produce near-term credible progress toward these incredible possibilities. An introduction to the emerging scientific possibilities from which such solutions can be sought is also presented.

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MEASUREMENT OF REPULSIVE QUANTUM VACUUM FORCES

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ABSTRACT

Quantum electrodynamics predicts that empty space (the quantum vacuum) contains a large amount of energy that corresponds to the lowest energy state (energy >0) of the electromagnetic field. Surfaces in the vacuum can experience forces that arise from the disturbance in the vacuum energy. The presence of attractive "Casimir" forces between uncharged, parallel, metal plates has been accurately verified in the last several years. Theoretical calculations have suggested the presence of repulsive vacuum forces for certain geometrical configurations. Here we describe an experiment in progress that is designed to determine if repulsive vacuum forces exist. In the experiment we measure the force exerted on a 200 um diameter metallized sphere mounted on an Atomic Force Microscope (AFM) that is placed very close to an array of gold microcavities. Observing a repulsive force on the sphere would verify the existence of repulsive forces. The ability to create attractive and repulsive vacuum forces by means of the geometry of the surfaces may permit the construction of devices that use ubiquitous vacuum energy in ways that assist with the space travel mission of NASA.

INTRODUCTION

Understanding the nature of vacuum forces and vacuum energy and how to manipulate this energy to obtain desired forces is a prerequisite to using these ubiquitous natural resources in any space application[1]. The theory for vacuum forces and quantum vacuum energy comes from Quantum Electrodynamics (QED), the theory of the interaction of matter and light[2]. **The role of the quantum vacuum is pervasive in modern physics. For example, it is involved in the calculation of atomic energy levels, the magnetic moment of the electron, the mass of elementary particles, spontaneous emission, dispersion forces between molecules, the large-scale structure of space-time.** **The experiment discussed in this paper is part of a three-year effort to begin to build, step by step, the knowledge base necessary for vacuum engineering. Our objective is to develop theoretical models of elementary systems that utilized vacuum forces and energy, to understand how these models behave, and then to explore some of these models experimentally. Since the critical dimensions required for these devices are typically micron to submicron, the experimental research utilizes microfabrication technology, and the methods developed for MicroElectro-Mechanical Systems (MEMS).**

In space applications the application of vacuum energy systems might be power generation, propulsion itself, or the manipulation of the metric of space-time itself by the creation of regions of positive and negative energy density[3]. It is too early to determine if such developments are possible or to be able to clearly determine the role of vacuum energy in future space applications. If we can develop technologies for space travel that utilize vacuum energy, it is very convenient since this energy is pervasive throughout the universe.

Fifty years ago, Casimir predicted that the modifications to the vacuum energy arising from the presence of two uncharged, parallel, metal plates would cause the plates to attract each other. This attractive Casimir force varies as the inverse fourth power of the separation. At a separation of 10 nm the force/area is about 1 atm. In 1997 the prediction of Casimir was verified for the first time. In 1998 precision measurements corroborated the predictions of an attractive vacuum force between neutral parallel plates to an accuracy of several percent. **In March 2001, scientists at Lucent Technology used attractive parallel plate vacuum forces (Casimir forces) to actuate a MEMS torsion device[4]. Other MEMS devices using vacuum energy have been proposed. [5]**

Recent calculations have indicated that forces due to the quantum vacuum predicted by QED depend very strongly on the geometry of surfaces. For certain rectangular metal cavities, QED predicts the existence of repulsive forces on the walls of the cavity[6]. **In this paper we describe the current status of the first experiment specifically designed to measure repulsive forces due to modifications in vacuum energy density achieved by using metal surfaces.** The vacuum force is measured by means of an Atomic Force Microscope using a 200 um diameter metallized ball placed on the end of a calibrated cantilever. Our model suggests that a repulsive force on the ball would be observed when it approaches within 10's of nanometers from the top of an array of rectangular cavities, each of which is 100nm across and 1 um deep, patterned in gold using x-ray photolithography (Figure 2). For small separations between the surface of the sphere and the top of the cavity array, we are approximating an array of closed cavities, which, according to a QED calculation, exhibit repulsive forces. **The force between the sphere and the cavity array is modeled numerically, with heuristic approximations, to be compared to the measured force. It is important to note that no rigorous method has yet been developed to calculate the vacuum force between any two non-planar conducting surfaces using QED.** Only the parallel plate problem has been solved. Indeed there is some disagreement that a repulsive Casimir force should ever be present between two separate bodies[7]. Measurement of repulsive forces between separate conducting bodies may be expected to stimulate new developments in QED.

If our experiment verifies the existence of repulsive vacuum forces, then it may be possible to utilize repulsive forces as well as attractive vacuum forces in microelectro-mechanical systems (MEMS). The existence of attractive and repulsive Casimir forces might permit the development of a variety of novel MEMS devices of potential use to NASA.

Quantum Electrodynamics (QED), Vacuum Energy and Casimir Forces

Quantum Electrodynamics (QED), the theory of the interaction of electromagnetic fields and matter, has made predictions of atomic energy levels and electron magnetic moments that have been verified to 1 part in 10^{12}, which makes QED the most precisely verified theory in science[8,9]. In order to achieve this accuracy, QED predictions have to include the interaction of matter with "empty space" or, more accurately, the quantum vacuum[10].

Some predictions of QED are less enthusiastically received by the physics community than others. One of the confounding predictions of QED is an energy density in empty space that is many orders of magnitude greater that the energy density of matter itself[11]. For years this feature of QED was dismissed as of no physical significance. However, observable forces can result when surfaces are present that alter this vacuum energy density. About 50 years ago, Phillips Laboratory physicist H.G.B. Casimir predicted the presence of an attractive quantum vacuum force between neutral, parallel, metal plates[12]. In the last three years, experiments have accurately confirmed this prediction of QED for the first time, verifying the existence of attractive vacuum forces between conductive surfaces[13,14,4]. The parallel plate Casimir force goes as the inverse fourth power of the separation between the plates. At a separation of 100 nm the predicted force/area is equivalent to about 10^{-4} atm.; at 10 nm it is about 1 atm.

BACKGROUND

Since most aerospace researchers do not have backgrounds in quantum systems, we provide a brief background to motivate our study. It is certainly not obvious that there should be any energy at all in empty space, much less a very large amount! Nor is obvious why there should be forces due to the vacuum fluctuations. The evidence for this theoretical conclusion lies in numerous well verified experiments on atomic energy levels, the magnetic moment of the electron, the behavior of liquid helium, and the scattering of elementary particles[15].

Vacuum energy is a consequence of the quantum nature of the electromagnetic field, which is composed of photons. A photon of frequency ω has energy $\hbar\omega$, where $\hbar$ is Planck's constant. **The quantum vacuum can be interpreted as the lowest energy state (or ground state) of the electromagnetic (EM) field that occurs when all charges and currents have been removed, and the temperature has been reduced to absolute zero. In this state no ordinary photons are present. Nevertheless, because the electromagnetic field is a quantum system, like an atom, which has internal motion even at absolute zero, the energy of the ground state of the EM field is NOT zero.** Although the average value of the electric field <E> vanishes in the ground state, the Root Mean Square

(RMS) of the field <E^2 > is **not** zero. Similarly the RMS of the ground state magnetic field <B^2> is not zero. Therefore the electromagnetic energy in the ground state, which from classical electrodynamics is proportional to <E^2> + <B^2>, is not zero. **A detailed theoretical calculation tells us that the electromagnetic energy in each mode of oscillation with frequency ⎯ is ½○⎯, which equals one half of the amount of energy that would be present if a single "real" photon of that mode were present.** Adding up ½○⎯ for all possible modes of the electromagnetic field gives a very large number for the vacuum energy E_0 in the quantum vacuum:

$$E_o = \tfrac{1}{2}\sum_i \hbar\omega_i \qquad (0.1)$$

The resulting vacuum energy E_0 is infinity unless a high frequency limit is used.

Inserting surfaces into the vacuum causes the modes of the EM field to change. This change in the modes that are present occurs since the electromagnetic field must meet the appropriate boundary conditions at each surface[16]. **Surfaces alter the modes of oscillation and therefore the surfaces alter the energy density corresponding to the lowest state of the EM field.** In actual practice, the modes with frequencies above the plasma frequency do not appear to be significantly affected by the metal surfaces since the metal becomes transparent to radiation above this frequency. In order to avoid dealing with infinite quantities, the usual approach is to compute the finite change in the energy of the vacuum ƛ⎯0 due to the presence of the surfaces[17]:

$$\Delta E_0\begin{bmatrix} change\cdot in\cdot vacuum\cdot \\ energy\cdot due\cdot to\cdot sufaces\end{bmatrix} = E_0\begin{bmatrix} energy\cdot in\cdot \\ empty\cdot space\end{bmatrix} - E_S\begin{bmatrix} energy\cdot in\cdot space\cdot \\ with\cdot surfaces\end{bmatrix} \qquad (0.2)$$

where the definition of each term is given in brackets. This equation can be expressed as a sum over the corresponding modes:

$$\Delta E_0(due\cdot to\cdot sufaces) = \tfrac{1}{2}\sum_{n}^{\substack{empty\\space}} \hbar\omega_n - \tfrac{1}{2}\sum_{i}^{\substack{surfaces\\present}} \hbar\omega'_i \qquad (0.3)$$

The quantity ΔE_0, which is the change in the vacuum energy due to the presence of the surfaces, can be computed for various geometries. The forces F due to the quantum vacuum are obtained by computing the change in the vacuum energy for a small change in the geometry. For example, consider a hollow conducting rectangular cavity with sides a_1, a_2, a_3. Let en(a_1, a_2, a_3) be the change in the vacuum energy due to the cavity, then the force F_1 on the side perpendicular to a_1 is:

$$F_1 = -\frac{\partial en}{\partial a_1} \qquad (0.4)$$

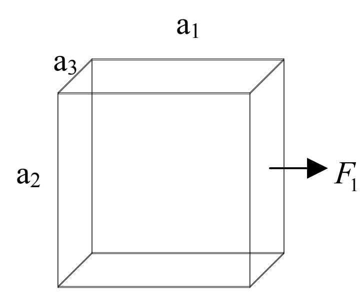


Figure 1. Geometry of rectangular cavity.

Equation (0.4) also represents the conservation of energy when the wall perpendicular to a_1 is moved infinitesimally[18]:

$$\delta en = -F_1\delta a_1 \qquad (0.5)$$

Thus if we can calculate the vacuum energy as a function of the dimensions of the cavity we can compute derivatives which give the forces on the surfaces. For uncharged parallel plates with a large area A, very close to each other, this equation predicts an attractive or negative force between the plates:

$$F_{att} = -\frac{\pi^2}{240}\frac{\hbar c}{d^4}A \qquad (0.6)$$

This force is called the parallel plate Casimir force, which was measured in three different experiments in the last three years[13,14,4]. The

Casimir force has only been computed and measured for this very large parallel plate geometry.

QED makes some unexpected predictions about Casimir forces in other geometries that have never been verified. For conductive rectangular cavities, the vacuum forces on a given face can be repulsive (positive), attractive (negative), or zero depending on the ratio of the sides[6]. **We are particularly interested in measuring these repulsive Casimir forces. Verifying the existence of such forces would have important implications in quantum electrodynamics and would be an important step to utilizing Casimir forces in a variety of MEMS devices.**

DESCRIPTION OF THE EXPERIMENT

Atomic Force Microscope

It is not practical to directly measure the force on one wall of a submicron metallic cavity. Hence another approach is needed. We chose to use an Atomic Force Microscope (AFM), which can provide a very sensitive measure of forces into the piconewton range (10^{-12} Newton). The AFM employs a 300 um long micromachined silicon nitride cantilever with a 200 um metallized sphere on the end that can be used to probe the vacuum energy density in the neighborhood of a rectangular micromachined cavity with no top surface[19] (Figure 2). When the sphere experiences a force, the cantilever is deflected. The deflection of the sphere is measured by shining a laser diode onto the reflective surface of the cantilever. The reflected light is collected in a photodiode that is divided into two adjacent regions. As the spot of light moves during a deflection, the ratio of current from the two regions changes, giving a sensitive quantitative measure of the cantilever deflection. It is possible to measure deflections of several nanometers in this manner. The cantilever is calibrated by determining the cantilever deflection for a known electrostatic force. The high precision of this experiment is made possible by the use of a Molecular Imaging AFM system that was specially developed at the University of Alabama at Huntsville for vacuum operation. With the very small distance (much less than the mean free path of the molecules) between the sphere and cavity, gas molecules can become effectively trapped, taking hours to remove under vacuum. For the most reliable measurements it is necessary to remove the trapped molecules and operate at a sufficiently low vacuum. Trapped molecules may result in a squeeze film damping force because the cantilever is always vibrating slightly.

The AFM stage was connected to a vacuum flange with the necessary feedthroughs. The sample is mounted and aligned when the AFM is in air (Figure 3a). Then the AFM is inserted into the vacuum chamber and the flange bolted in place using copper gaskets (Figure 3b). The vacuum without the AFM is 10^{-8} torr; inserting the AFM reduces the vacuum to about 10^{-4} torr. The system is pumped with a turbo molecular pump and an ion pump. The AFM is housed in a clean room environment.

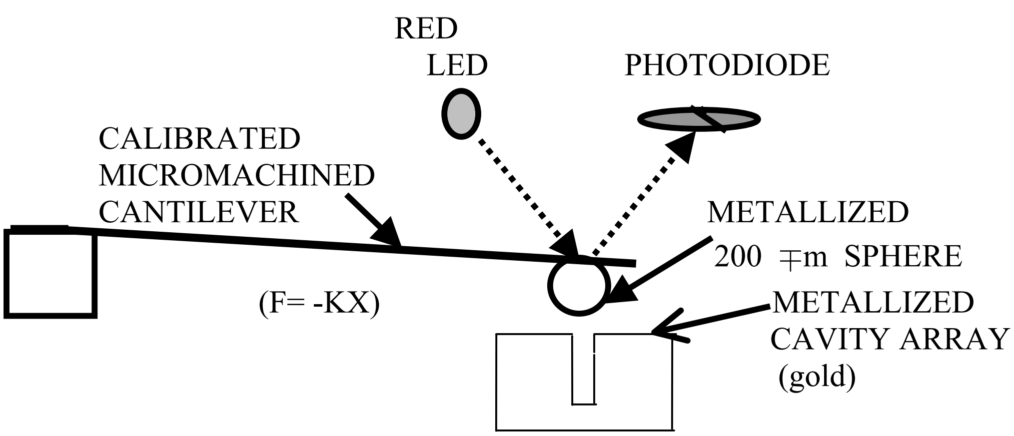


Figure 2. Schematic of Atomic Force Microscope measurement of the vacuum force between a metallized sphere on a cantilever and a rectangular cavity etched in gold (not to scale).

The force constant of the AFM cantilever is measured by using electrostatic forces. A know potential is applied between the test surface and the cantilever, and the deflection of the cantilever due to this potential is measured. The corresponding force is calculated using a finite element classical electrodynamic calculation. The system was tested by making measurements on the attractive Casimir force between the metallized sphere and a flat gold region and comparing these results to know values.

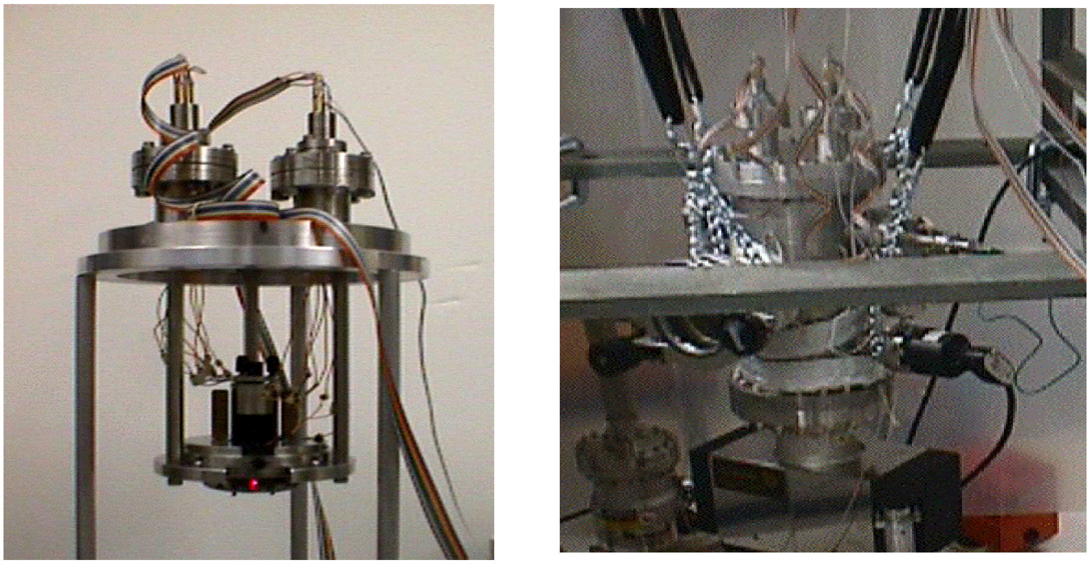


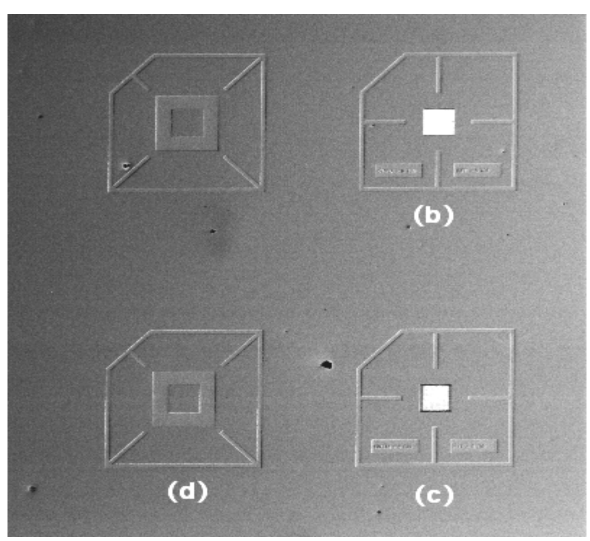
Figure 3. (a) shows the AFM stage below the vacuum flange, connected to the vacuum feedthroughs above. (b) shows the AFM mounted inside a small, stainless steel, vacuum chamber supported by elastic cords to reduce vibration.

Cavity Design

Numerical computations were done of the change in the vacuum energy and vacuum forces for a variety of rectangular cavities using QED methods[1,6]. The goal was to determine a cavity geometry that 1) would yield a large, detectable, repulsive force, 2) the repulsive force would change slowly with distance, and 3) that could be fabricated. The second requirement was deemed advisable to insure that the repulsive vacuum force would not vary too rapidly as the distance between the sphere and the opening of an etched rectangular cavity changed. The final cavity design selected was 0.1 um x 100 um x 1 um (width x length x depth), with walls that are 0.1 um thick.

Wisconsin Center for X-Ray Lithography. The cavity arrays fabricated are 100um x 100 um square, with cavity walls 0.5 um deep, with thickness t between 250 and 300 nm thick, and cavity widths w between 125 and 150 nm. Calibration surfaces for the AFM were also included in the design. The overall test pattern design is shown in Figure 4, and a portion of one of the cavity arrays closest to the target design is show in Figure 5.

Figure 4. A SEM photograph of a portion of the test die, showing two 500 um square calibration patterns on the left, and two 500 um square cavity array regions on the right side. The center of each calibration pattern is a flat gold surface at the same level as the bottom of the cavities, surrounded by a gold surface at the level of the top of the array. The white regions on the right are the 100 x 100 um cavity arrays. The rectangular regions below the arrays indicate the nominal cavity width and wall thickness (50 x).



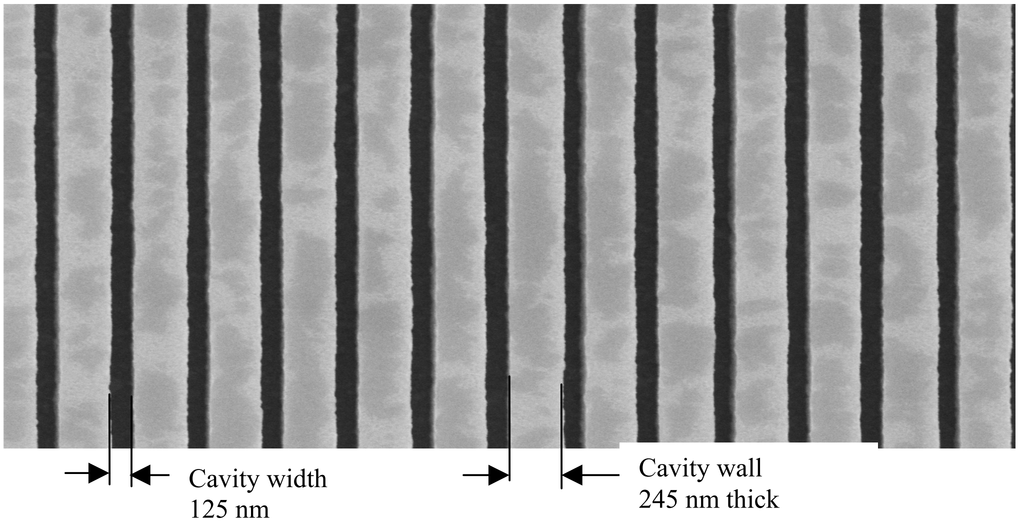


Figure 5. SEM photograph of portion of the gold cavity array. Each cavity is actually100 um long. The entire array is 100 um wide (magnification 37,000; 15kV).

<u>**Theoretical Modeling**</u>
As mentioned previously, no QED method has been developed to compute the vacuum forces between separate conducting surfaces. There is no theoretical model for such a configuration of two separate surfaces in the literature; no QED calculation of Casimir forces have been done except for planar or slightly rough planar surfaces. Hence we developed a heuristic model in which we assume the force on the sphere arises from two effects: 1) the attractive force due to the proximity of the sphere to the flat top surfaces of the cavity walls (parallel plate attractive Casimir force Eq 1.6), and 2) the repulsive forces on the sphere due to the cavity. The geometry of the experiment is shown in Figure 4.

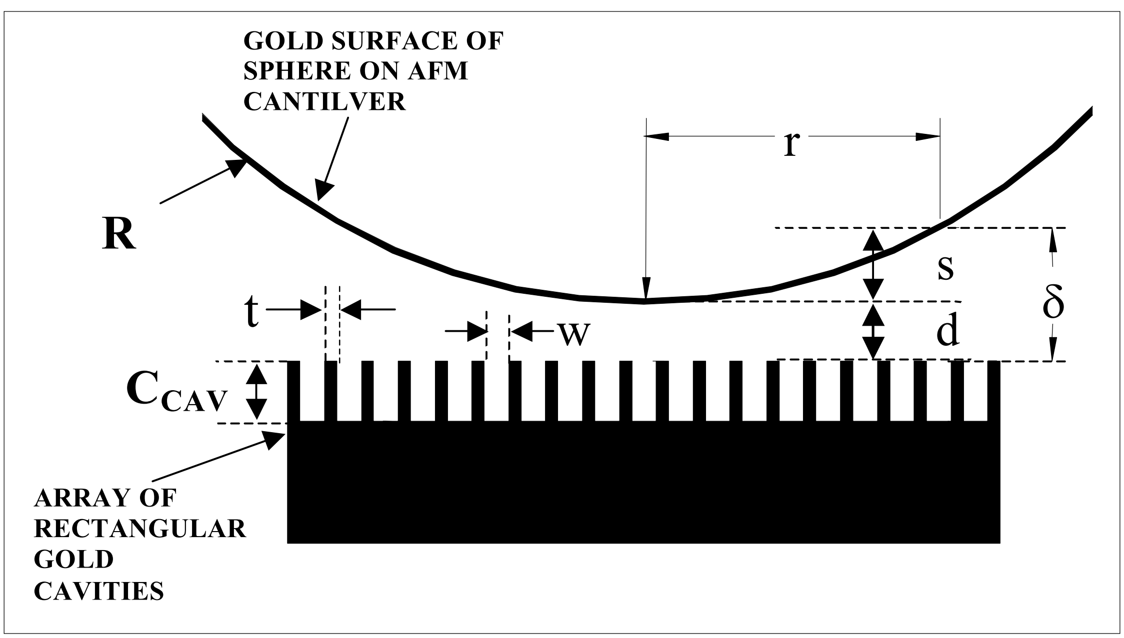


Figure 6. Distance definitions, illustrating actual cavity depth (C_{CAV}), individual cavity width (w), cavity wall thickness (t), separation distance (*d*), local sag (*s*), and local separation distance (δ).

The sphere has radius *R*. The closest point or tangent point of the sphere is located a distance *d* above the tops of the cavities. The local separation distance is $\delta = d + s$, where *s* is the local sag of the spherical surface. The quantity δ can be given as a function of r, the horizontal distance from the tangent point of the sphere. The expression for the attractive Casimir force Eq. 0.6 is actually derived for an infinite parallel plate geometry in which the lateral dimensions of the plates are much bigger than the spacing between the plates. Since this condition is not met for spacing d>t (width of cavity wall), we applied a correction factor to the attractive force, obtaining the expression for the attractive force:

$$F_{att}(r) = \frac{\pi^2}{240}\frac{\hbar c}{\delta(r)^4} A_w \left(\frac{t}{t+\delta(r)}\right) \qquad 0.7$$

where we used the local separation distance $\delta(r)$, □□ t is the thickness of the cavity wall, and A_w is the area of the tops of the cavity walls. The QED calculation of the repulsive Casimir force was for a closed, rectangular metallic box. Therefore we need a method to correct for the experimental geometry in which there is a gap at the top of the box. For the repulsive cavity force, we used the computed force for a closed cavity of width "w" with a depth equal to the actual depth (C_{CAV}), and multiplied it by an approximate correction factor K(r) suggested by theoretical analysis[20]:

$$K(r) = \left(\frac{C_{CAV}}{C_{CAV}+\delta(r)}\right)^3 \left(\frac{w}{w+\delta(r)}\right) \qquad 0.8$$

Eqs. 0.7 and 0.8 predict that both forces decay rapidly as the separation distance is increased. Rather than sum over individual cavities, we used an effective pressure distribution, which is an area-weighted combination of the cavity force and wall force. This provides a pressure distribution *p*(*r*) over the surface of the sphere, where *r* is the radial coordinate. This pressure distribution depends on the geometry, including the separation distance, *d*.

To obtain the total force on the sphere, we integrated the pressure *p(r)* on the bottom of the sphere due to the sum of the forces, i.e.,

$$F = \int_0^{R/2} 2\pi r p(r) dr \qquad 0.9$$

Figure 7 shows a plot of the force F as a function of the separation d for a cavity array with 1) the target dimensions, namely w= 0.1 um wide with t=0.1 um thick sidewalls and 1.0 um deep, and 2) the best actual cavity dimensions fabricated, namely w=0.125 um wide cavities with t=0.250 um sidewalls, 0.5 um deep.

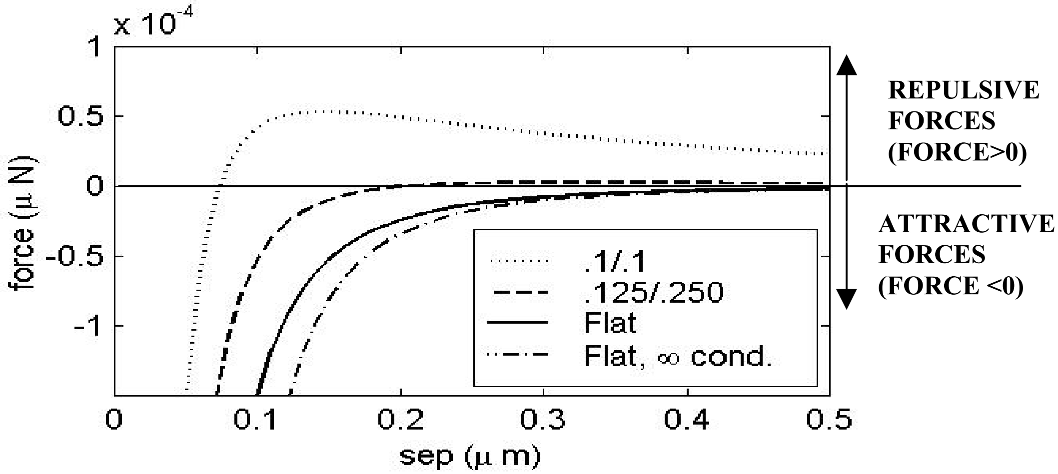


Figure 7. Force vs. distance d for a 100 um square cavity array with 1) the target dimensions, cavity width w = 0.1 um, wall thickness t=0.1 um, depth Ccav = 1.0 um deep; 2) the best fabricated cavity, width w=0.125 um, thickness 0.250, depth 0.5 um deep. The two uppermost curves show the force for the sphere above the cavity arrays. The solid curve shows the attractive force for a flat surface, with no cavities. Conductivity corrections are included. The sphere diameter is 210 um.

Also shown for comparison, is the calculated force (labeled Flat in the figure) for the case of a sphere over a flat surface, i.e. with no cavities at all in the gold. The known correction factors for finite conductivity for the force between parallel plates were used except for the curve labeled infinite conductivity. For the lack of any other theory, the same conductivity correction factors were applied to the cavity geometry.

For the parallel plate case, the force is always negative or attractive, and the force decreases rapidly (Eq 1.7 integrated over the hemisphere, or approximately as $-1/\delta^4$) with the separation δ. The component with upward curvature in the cavity array curve is due to the repulsive force (Eq 1.8 integrated over the hemisphere, which goes approximately as $1/\delta^3$). Because of the more rapid inverse variation of the attractive force, the attractive force dominates at very small separations d, going to zero more rapidly than the attractive force. Hence the repulsive force dominates at larger separations, above about 0.1 um. From QED we expect that smaller cavities would give larger repulsive forces; and thinner walls give smaller attractive forces. The predictions of the model show this desired behavior, and the model calculations appear to go smoothly into these known curves for flat surfaces. It appears that the repulsive force is on the edge of detectability for the cavities fabricated.

CONCLUSIONS

Quantum electrodynamics, which has made predictions which have been verified to 1 part in 10^{12}, predicts the existence of a large, ubiquitous, zero-point vacuum energy density in empty space. The question arises: Can we make use of this energy in some way to facilitate space travel, such as energy generation, propulsion, or creation of wormholes? It is too early to determine if such developments are possible or to be able to clearly determine the role of vacuum energy in future space applications. Our investigation begins with what we do know about vacuum energy, and extends those boundaries. We know that QED predicts that as a consequence of this energy, an attractive force will exist between uncharged, parallel, metal plates. In the last few years, accurate measurements have confirmed the existence of this force. QED also predicts the existence of repulsive forces in small rectangular metal boxes in which one dimension is much less than at least one of the other two dimensions. Although no one has done a rigorous calculation, it appears probable, based on theory, that a repulsive force should exist between two separate surfaces that closely approximate such a closed box. Vacuum forces that are repulsive because of the geometry have never been observed.

We have designed an experiment to measure repulsive vacuum forces. A model has been developed to predict the vacuum force on a metallized sphere attached to a cantilever on an AFM when the sphere is brought to within nanometer distances of an array of gold cavities. An AFM that operates in vacuum at 10^{-4} torr has been constructed to perform the experiment. Based on our model calculations, it appears we should be able to measure repulsive vacuum forces using the AFM, provided the cavities have small enough dimensions. Based on our model calculations (Figure 7) the cavities fabricated to date (125 nm width, 245 nm wall thickness) have dimensions that may be too large to provide a clear indication of a repulsive force. We need to utilize cavities with dimensions of approximately 100 nm width, 100 nm wall thickness in order to have a clear indication of repulsive forces. The University of Wisconsin Center for NanoTechnology is currently upgrading one of its synchrotron exposure systems in order to provide features of this size.

If we can obtain repulsive as well as attractive vacuum forces by a suitable choice of geometry, we are one step closer to being able to design a variety of novel MEMS devices using vacuum energy that could assist in attaining some of the NASA objectives for space travel.

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SEARCH FOR EFFECTS OF ELECTRIC POTENTIALS ON CHARGED PARTICLE CLOCKS

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ABSTRACT

Results of experiment to confirm a theory that links classical electromagnetism with the geometry of space-time will be described. The theory, based on the introduction of a Torsion tensor into Einstein's equations and following the approach of E. Schrödinger, predicts effects on clocks attached to charged particles, subject to intense electric fields, analogous to the effects on clocks in a gravitational field. We show that in order to interpret this theory, one must re-interpret all clock changes – both gravitational and electromagnetic – as arising from changes in potential energy and not merely potential. The clock is provided naturally by proton spins in hydrogen atoms subject to Nuclear Magnetic Resonance trials. No frequency change of clocks was observed to a resolution of 6×10^{-9}. A new "Clock Principle" was postulated to explain the null result. There are two possible implications of the experiments: (a) The Clock Principle is invalid and, in fact, no metric theory incorporating electromagnetism is possible; (b) The Clock Principle is valid and it follows that negative rest mass cannot exist.

INTRODUCTION

The goal of the present work is to investigate an electromagnetic alternative to exotic physics for the purpose of coupling matter to space-time. Electromagnetic forces have distinct advantages. They are 10^{40} times stronger than gravity. They can be manipulated at will. Resources to create intense fields of virtually any geometry are readily available. However, there is currently no accepted theory linking electrodynamics directly with the geometry of space-time other than to curve it via extremely high energy densities. The mainstream approach taken is "bottom up", attempting to unite all forces in the context of quantum gauge field theory which has to-date been successful in unifying the weak and electromagnetic forces and describing the strong force in what is known as "the standard model". Gravity and therefore space-time geometry remains isolated from the internal geometry of gauge theory. If such a theory could be found and even its simplest predictions tested and verified, then there would be hope that electromagnetic coupling to space and time might be possible. This could lead to new interpretations and possibly new effects in gravitation and electromagnetism.

The experiments described in this work measure the predictions of a theory[1], linking space-time geometry and electrodynamics. This is grounded upon E. Schrödinger's later works on gravitation theory[2]. In his work, Schrödinger attempted to link electromagnetism to geometry through a non-symmetric affine connection (Torsion tensor). He failed at the attempt, primarily because of an error of oversight. The theory upon which the present work is based corrects this error[3], resulting in the definition of a new type of affine connection – an electrodynamic connection – that precisely matches Schrödinger's concepts.

THEORY

We describe a simplified theory and shall only write the new field equations and their solutions for the present case. The theory is summarized in the BPP final report*. The governing equations are:

$$G_{\mu\nu} = -\frac{\kappa}{2} u^{\sigma} (F_{\nu\sigma;\mu} + F_{\mu\sigma;\nu}) \tag{1}$$

$$F^{\mu\tau}_{\ ;\tau} = 0 \quad ; \quad F_{\mu\nu;\sigma} + F_{\nu\sigma;\mu} + F_{\sigma\mu;\nu} = 0 \tag{2}$$

$G_{\mu\nu}$ is the Einstein tensor. $F_{\mu\nu}$ is the Maxwell electromagnetic field tensor. u^{λ} is the test particle 4-velocity and κ = -e/mc2, the charge/mass ratio of the test particle. Greek indices range from 0, the time index, to 1,2,3, the space indices. Equation (1) is the modified Einstein equation including Electrodynamic Torsion. Equations (2) are the usual covariant Maxwell equations. Selecting a metric for an appropriate

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geometry results in a set of solvable differential equations coupling the metric and electromagnetic field variables.

Ideal Experiment

The theory predicts that a particle of charge e, and mass m, immersed in a suitable electric field but unshielded and supported will see, in its rest frame, a time differing from the proper time of an external observer arising from the electrostatic potential at its location. In general, from the theory, the time shift in a clock interval is related to the potential difference between two points:

$$\frac{d\tau_2}{d\tau_1} = 1 + 2\kappa(\varphi_2 - \varphi_1) \quad (3)$$

This equation is exactly analogous to that for the gravitational red shift.

One possible clock for such a test is Nuclear Magnetic Resonance. A proton placed in an intense electric field within a radio-frequency transverse field "H_1" coil aligned orthogonally to a uniform magnetic field, H_0, is resonant at the Larmor frequency, $\omega = \gamma H_0$, where the gyromagnetic ratio, γ, for the proton spin is proportional to e/m. We thus have a natural clock. From eq. (3) we expect the proton's clock frequency to depend on its relative positions r_1 and r_2:

$$\omega(r_2) = \omega(r_1)\left[1 + 2\kappa(\varphi_2 - \varphi_1)\right] \quad (4)$$

The Larmor field distribution is then given by

$$H(r_2) = H(r_1)\left[1 + 2\kappa(\varphi_2 - \varphi_1)\right] \quad (5)$$

From this it is straightforward to calculate the NMR lineshape and shift that will result when the electric field is turned on as compared to the field off. Under ideal circumstances, for a supported proton in a 8T magnetic field with a 5kV/cm electric field, a line shift and broadening of approximately five parts per million is expected. The expected NMR lines are modeled in the "Experiments" section.

Present Approach

In practice it is experimentally difficult to "support" a charged particle. Generally, this can be accomplished electromagnetically, but then, by definition, the electric field and force at the particle location must vanish since the charge does not accelerate. The approach we have chosen uses the proton in a hydrogen atom. It is supported electromagnetically. The consequences of this approach will be the main subject of the conclusions of this work. A detailed description of the three experiments performed follows.

EXPERIMENTS

Three experiments were performed: A temporally and spatially constant potential applied to the proton in the hydrogen atom; A time-varying but spatially constant potential applied to the proton in the hydrogen atom; A hydrogen atom physically displaced through an intense electric field.

Experiment 1 – Constant potential

A 354 MHz, 8.4 Tesla NMR system was chosen for the experiments. This magnet has a field homogeneity of 0.1 ppm or about 35 Hz, more than sufficient to resolve small effects. The proton sample was Benzene. The initial experiment was a simple free induction decay (FID) with the E-field on vs. off. The sample was enclosed in a 2mm thick aluminum can (Fig. 1) placed at high potential. Thus the E-field will vanish in the interior of the can at the sample but there will remain a constant potential. The voltage terminal (sample chamber) could be set + or – with respect to ground and the NMR FID was monitored.

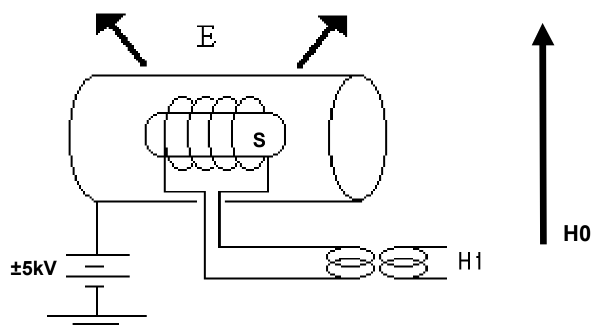

Figure 1. NMR "can" arrangement. External magnetic field, H0, is perpendicular to the radio frequency field, H1, applied through a coil wrapped around the proton sample, S. The 5kV electric field is applied outside the can leaving a constant 5kV potential inside.

A field homogeneity of 10 ppb was achieved for the 8.4T field, sufficient to resolve the smallest predicted effects. The observed line shift, was $\Delta\nu/\nu \le 0 \pm 1.0\text{x}10^{-9}$, consistent with a null prediction of both classical E&M and the present theory. The null result is consistent with both classical theory and the present one.

Experiment 2 - Time-varying potential

The second experiment, a time-varying potential applied to the proton in the hydrogen atom, was initially expected to produce an effect. However, it was found during the course of this program that this theory was also invariant under a pure time-varying potential[5], a result consistent with the classical "Lorentz gauge condition" which is the relativistic generalization of the Coulomb gauge condition. That is, it states that the potential is also arbitrary to an additive time-derivative of a scalar. Thus, a null result was also expected and was observed. A "spin-echo" experiment was performed to observe any phase shift introduced by the time varying electric field. Extreme care was taken to calibrate the system to ensure that any small phase shift could be identified and that stray currents would not affect the data. Upon application of a 5KV step-function (20 ms risetime) between the aluminum can and ground in both turn-on and turn-off modes, the observed shift in the NMR line was $\Delta\nu / \nu \leq 0 \pm 1.0\text{x}10^{-11}$.

Experiment 3 - Physical displacement of Hydrogen atom through high electric field

For the third and final experiment, hydrogen in benzene at room temperature was gravity-flowed between two electrodes, an upper one at ground potential and a lower one at +5000 V, both situated in the NMR coil in the external 8.4T magnetic field while NMR was performed with the electric field on and off. The electrodes were copper discs placed in the 3mm I.D. of glass tubing and connected to a high voltage source through glass/epoxy seals. The electrode spacing was 1.0 cm giving an average electric field of 5000V/cm. The 2-turn NMR coil diameter was 1.5 cm ensuring that the HV region was inside the coil. The coil was untuned to avoid radiation damping since the signal was already very large. Figure 2 shows the NMR coil system arrangement and a photo of the open chamber.

An NMR FID experiment was performed with and without flow. A 20-30 ms T_2 was obtained by careful adjustment of the B-field shim coils. The NMR line and effects of flow without the presence of an E-field were modeled. The T_2 value gives a line width of approximately 17 Hz ($\Delta f = 1/\pi T_2$). Figure 3 shows the measured NMR line with voltage off as a function of flow velocity through the coil varying from 3 cm/s to 50 cm/s. Since the FID has a time constant of 20-30 ms, the proton must stay in the H1 field at least this long in order to contribute a significant time-shift signal arising from the maximum 5kV potential change. This corresponds to a flow speed of 15-30 cm/s, the mid-range of the chosen flows. Note that the measured shift with zero volts is approximately 10 Hz, from 0 to 50 cm/s flow rate, in approximate agreement with the theoretical calculation, Figure 3. Figure 4 shows the predicted lines for a maximum potential of 5000 Volts. The shift is at least ten times that for zero volts.

For the flow experiment, the NMR line was obtained for voltage off, voltage on, and a dummy voltage on (voltage on but HV cable disconnected). The probe voltage was discharged when the dummy experiment was performed. Figure 5 shows data for flows of 0, 3, 6, 12, 25 and 50 cm/s with the voltage applied .

We note in Figure 5 that there is no change in the line positions greater than the FFT resolution of $\pm$ 2 Hz corresponding approximately to a line shift of $\Delta\nu / \nu \leq 0 \pm 6.0\text{x}10^{-9}$, at least a hundred times smaller than the predicted shift of Figure 4. Figure 3 is therefore representative of the results with applied field as well.

When the experiment was completed, the probe was disassembled and carefully inspected to ensure that all voltage connections were secure.

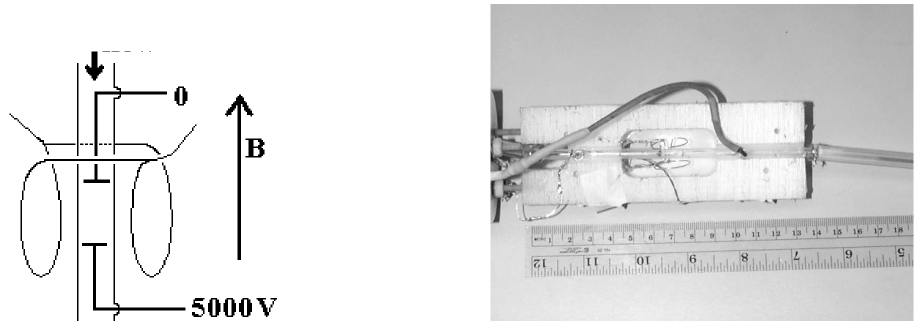

Figure 2. Diagram and photo of NMR coil and flow arrangement for E-field experiment

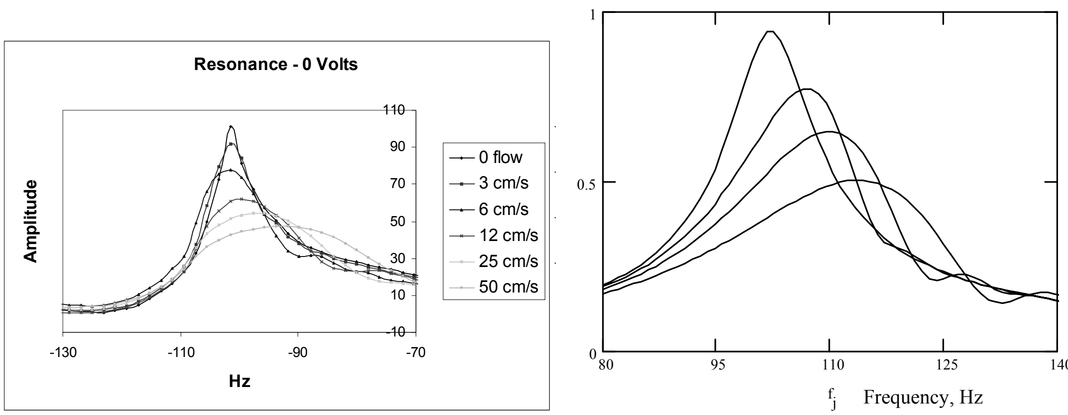

Figure 3. Measured NMR lines (left) and calculated (0,12,25,50 cm/s) for zero E-field and flows from 0 - 50 cm/s.

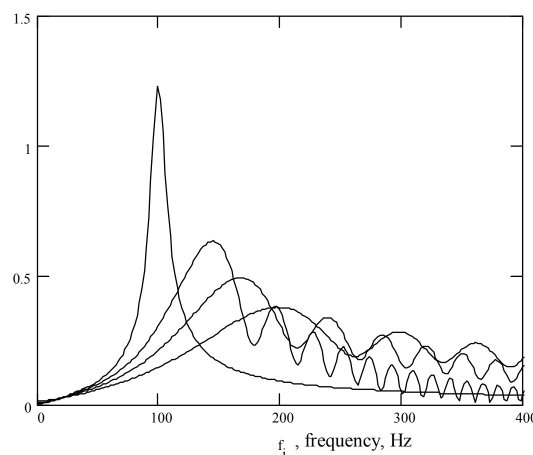

Figure 4. Calculated NMR lines for 5000V/cm E-field for flows of 0, 12, 25 and 50 cm/s.

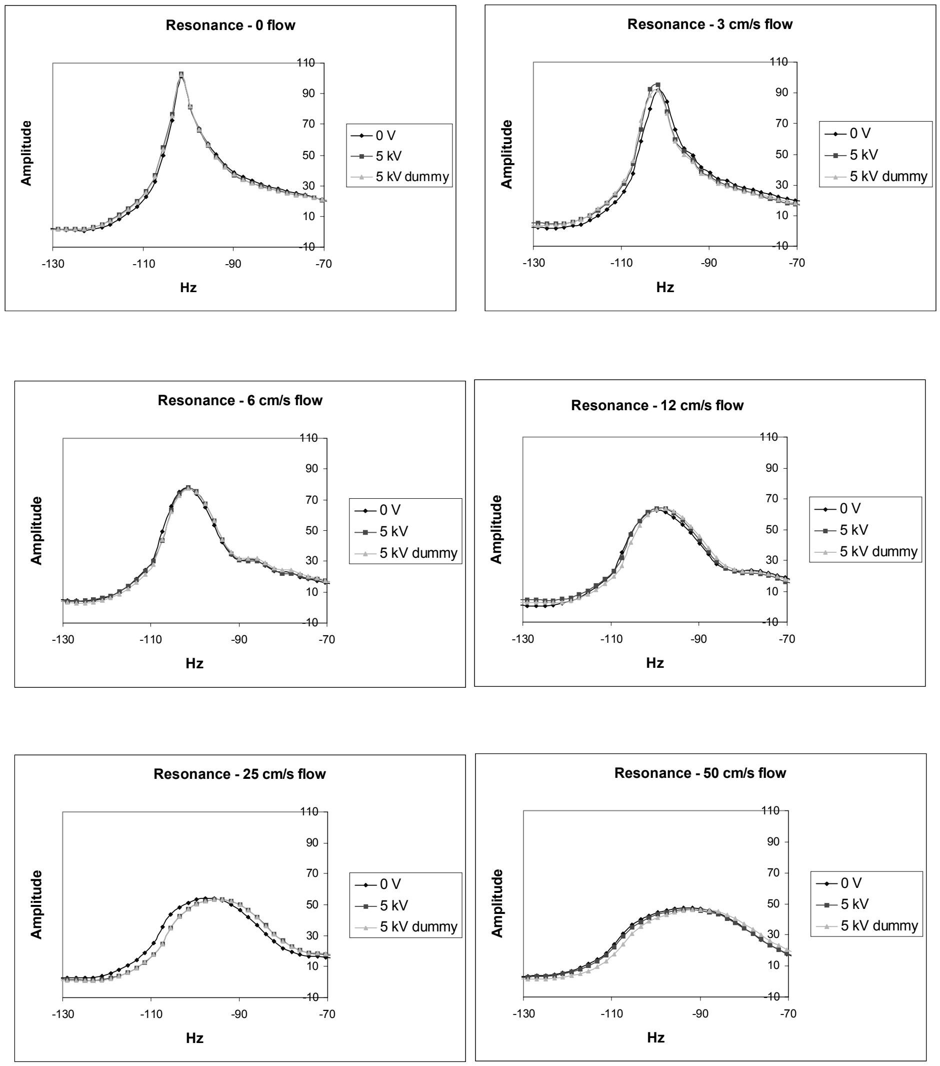

Figure 5. Measured variation in NMR line at 0, 6, 25 and 50 cm/s flow with applied voltage.

CONCLUSIONS

Experimental Conclusions

All three experiments showed null results. The first experiment, constant potential applied to the proton in the hydrogen atom, produced a null result as expected and explained earlier. The second experiment, a time-varying potential applied to the proton in the hydrogen atom, also produced a null result as expected and explained. From the second experiment we have learned that the present theory is relativistically Gauge Invariant in the context of Maxwell's equations – as it should be.

The third experiment, physical displacement of a proton in a hydrogen atom through an electric field, was expected to produce a frequency shift of 5ppm in the NMR line. No change was observed to high precision. This could be explained as follows. When a hydrogen atom is placed in an electric field, classically, only one effect is produced – an induced dipole moment of the atom resulting from the stretching of the electron orbital. Otherwise, no work is done on the hydrogen atom (except for the exceedingly small amount involved in stretching) since the work done on the proton is cancelled by the opposite work done on the electron(due to its negative charge) in the electric field. Furthermore, it is straightforward to show[4] that no work is actually done on the proton itself since the electric force on it is precisely balanced by an opposing force, in the field direction, from the electron.

Implied Conclusions

If we substitute potential energy change and therefore work done rather than simple potential in the metric, then the fact that no work is done on the proton because of the electron's influence can explain the null result. We now discuss the relation of work to the metric.

Relation of the Metric to the Lagrangian and Work Done

Let $\tilde{L}$ be defined as the specific Lagrangian or Lagrangian per unit rest energy,

$$\tilde{L} = \frac{(T - V)}{mc^2} \tag{6}$$

where T, V and m are the kinetic energy, potential energy and rest mass of the test particle respectively.

Suppose we are at rest at some height z in a gravitational field, so that $T=0$ and $V=mgz$, then $\tilde{L} = gz/c^2$. We have shown for weak fields and nonrelativistic speeds that the proper time element can be written in terms of the Specific Lagrangian and coordinate time element as:

$$d\tau = \sqrt{1 - 2\tilde{L}}\ dt \tag{7}$$

This describes the behavior of clocks. Consider two positions in the gravitational field z_1 and $z_2 = z_1 + h$. Assume a proper time interval $d\tau_1$ at z_1 and $d\tau_2$ at z_2. Then, for weak fields:

$$\frac{d\tau_2}{d\tau_1} = 1 - \frac{gh}{c^2} \tag{8}$$

We can rewrite this in terms of potential energy and Lagrangian rather than potential;

$$\frac{d\tau_2}{d\tau_1} = 1 - \frac{mgh}{mc^2} = 1 - (\tilde{L}_2 - \tilde{L}_1) = 1 - \Delta\tilde{L} \tag{9}$$

In general, a variation in the Specific Lagrangian results in a change in the clock rate. Referring more concisely to the metric for a single particle, *p,* we may express the Lagrangian change more clearly in terms of the net conservative work, W_c, done on *p.*

$$\Delta\tilde{L}_p = 1 - \frac{(\Delta T - \Delta V)}{m_p c^2} = \frac{\Delta T_p + W_c}{m_p c^2} \tag{10}$$

The weak-field, non-relativistic, metric for a given particle, p, acted upon by forces and hence net conservative work, W_{cp}, done upon it by all other particles in the field is given by

$$d\tau_p{}^2 = \left(1 - \frac{2W_{cp}}{mc^2}\right)c^2 dt_p{}^2 - dx_p{}^2 - dy_p{}^2 - dz_p{}^2, \tag{11}$$

We have rewritten the metric in this way because potential is not well-defined except through potential energy and work, where it is defined as work per unit mass in gravitation and work per unit charge in electromagnetism.

The Clock Principle

In the previous section we found a simple Lagrangian formulation that places gravitation on an equal footing with our theory in regards to changes in the temporal portion of the metric. The Lagrangian formulation deals with kinetic and potential energy changes. Clocks raised in a gravitational field are at rest in the two positions and can be slowly moved between them. Thus the Lagrangian becomes simply the negative change of potential energy(work done on) of the clock, moved from the lower position to the upper. However, we must be careful and can no longer use the word "clock" loosely. When we refer to "clock" henceforth, we mean the *mechanism of the clock*. Thus we mean that work is performed on the *mechanism*. Clearly all clock mechanisms are driven by energy changes. What is not as obvious is that the mechanism of any clock must reflect the proper time variations in a gravitational field. For example, the mass-spring mechanism of a simple clock must somehow change with different heights in a gravitational field. Similarly, a pendulum clock must exhibit changes in its mechanism. Even an atomic clock is subject to this consideration. This brings us to the ***first clock postulate***:

1) Every clock has a mechanism which must be held accountable for observed changes in its measurement of time.

We shall now examine the relationship between work and changes in clock time in a gravitational field. We use the notation "nc" to mean nonconservative and "c" for conservative forces.

Einstein Rocket -- Equivalence Principle for clock changes in a Gravitational Field

We shall employ the famous Einstein rocket "gedanken-experiment" to demonstrate our concepts. Consider a rocket lifting a mass, *m*, by a stiff wire in a gravitational field. Let us suppose that we adjust its thrust to precisely oppose the graviational pull on the mass. The rocket-mass system is now balanced and hovers, for example, at the surface of the earth. An arbitrarily small external force, $\vec{\varepsilon}$, may now raise the system to a height, *h*. This is shown in Figure 7. The force $\vec{\varepsilon}$ does no work on the system since it can be made arbitrarily small. However, upon rising a height h, due to the infinitesimal assistance of the guiding force, the rocket does work on the mass *m*. The potential energy of the mass is V_1 at the surface and V_2 at height *h*.

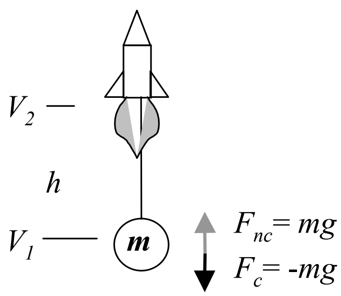

Figure 7. Balanced force configuration of a rocket-mass system

In this situation, the nonconservative force is that of the rocket. This is equal and opposite to gravity. We make the following definitions:

$$z_2 - z_1 = h \;;\; d\vec{s} = dz\hat{k} \;;\; \vec{g} = -g\hat{k} \tag{12}$$

Then the non-conservative work performed on the mass m by the rocket is

$$W_{nc} = \int_{z_1}^{z_2} \vec{F}_{nc} \cdot d\vec{s} = mgh \,. \tag{13}$$

and the conservative work done on m by gravity, opposing the rocket is:

$$W_c = -mgh = -(V_2 - V_1) = -\Delta V \tag{14}$$

<u>Einstein rocket replaced by negative mass</u>

Let us now reconsider the rocket of Figure 7. We can replace the rocket by negative mass equal in magnitude to the lower positive mass (Fig. 8). Earth's gravity repels negative mass and thus an amount *(-m)* will precisely balance the force of attraction on *m*, a situation equivalent to the rocket.

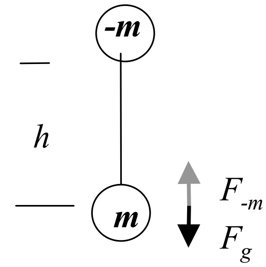

Figure 8. Balanced force configuration for rocket replaced by negative mass

We evaluate the work done in this situation. There are two forces acting on m, $\vec{F}_g$ and $\vec{F}_{-m}$. This time *both* forces are conservative. The total work done on the mass m is zero because there is no change in the kinetic energy, since $\vec{F}_{-m} = -\vec{F}_g$.

$$W_{total} = \int \vec{F}_g \cdot d\vec{s} + \int \vec{F}_{-m} \cdot d\vec{s} = \Delta T = 0 \tag{15}$$

However, now the total work done on m is conservative since, unlike with the rocket, there are no non-conservative forces acting. The rigid wire transmits the conservative force from *–m*. Thus we find:

$$W_c = W_g + W_{-m} = 0 \tag{16}$$

This model of a massive neutral dipole is exactly equivalent to an electric neutral dipole such as the proton and electron of a hydrogen atom in an electric field. In the latter case, the two forces acting on the proton, the external electric field and the opposing force of the electron are both conservative. The total conservative work on the proton is zero when the atom is moved a distance h through a known potential difference. That is precisely our experiment. There was no clock change observed.

This leads us to the ***second and third Clock Postulates***:

2) External conservative work done on a clock mechanism is responsible for changes in its rate when the motion of the clock can be neglected.

3) When the clock is not at rest, the change in its rate arises more generally from the change in the Specific Lagrangian for the mechanism.

The third postulate takes into account the change when there is kinetic energy present.

These postulates reconcile the observations and considerations of the present experiment with those observed for gravity. Therefore one should not expect to see a clock change in the imagined massive dipole experiment since there was no net conservative work done on m.

Inconsistency between General Relativity and existence of a neutral mass dipole

Now consider a clock on the mass *m* attached to the rocket. The mass *m* might itself be part of a clock mechanism. Upon reaching height *h*, the clock will change. But the mass *m* cannot distinguish between the pull of the rocket on the wire from that of the negative mass. In the case of the negative mass , the Clock Principle states that since no net conservative work is done on *m* , no clock change should be observed. So, there is a conflict here. It follows that:

Since we assume GR to be true, either the Clock Principle is false or a mass dipole cannot exist as the analogue of a charge dipole. Thus, if the clock principle is true, negative mass cannot exist. If the clock principle is false, then work and energy change are not related in general to time change. It follows that a metric theory of forces other than gravitation cannot be constructed.

Clock Conclusions

It is generally agreed that in order for a clock to indicate the passage of time, energy change in the mechanism is required. Thus, it appears that space is coupled to time through energy. When a clock is raised in a gravitational field, external work is performed on the mechanism. This permits a time change. If W_c =0 so that applied forces opposing conservative forces are also conservative, then there will be no observed clock change.

We have shown that if the clock principle is correct then ***negative mass cannot exist***. This does not preclude the existence of negative energy since the general energy-momentum relation has two roots,

$$E = \pm\sqrt{p^2c^2 + m^2c^4}$$

of which the positive root, in the rest frame of a particle of mass m (p=0), is the famous Einstein energy-mass relation.

ACKNOWLEDGEMENTS

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Tests of Mach's Principle with a Mechanical Oscillator*

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Abstract

James F. Woodward has made a prediction, based on Sciama's formulation of Mach's Principle in the framework of general relativity, that in the presence of energy flow the inertial mass of an object may undergo sizable variations, changing as the 2nd time derivative of the energy. We describe an attempt to observe the predicted effect for a charging capacitor, using a technique that does not require a reactionless force or any local violation of Newton's 3rd law of motion. We attempt to observe the effect of the mass variation on a driven harmonic oscillator with the charging capacitor as the oscillating mass. Positive and negative phase shifts in the oscillator motion with respect to the driving force are predicted to result from appropriately programmed inertial mass variations. The phase shift is constant, so that data may be accumulated over a very large number of oscillation cycles to insure high precision in the phase shift determination. We report on the predicted effect and the design and implementation of the measurement apparatus. At this time, however, we will *not* report on observations of the presence or absence of the Woodward effect.

Introduction

This is a status report on a new experiment to test a prediction based on general relativity and Mach's Principle, which has been supported by the Breakthrough Propulsion Program of NASA.

Einstein's Principle of Equivalence, a cornerstone of general relativity, asserts the exact universal identity of inertial mass and gravitational mass. However, the origins of inertia and its connection to gravitational mass remain obscure. Mach's Principle, the idea that inertia originates in the gravitational interaction of massive objects with the distant matter of the universe, is an attempt to unify gravitational and inertial mass, but it is not a part of general relativity. Dennis Sciama [1,2] attempted to improve this situation by showing that, for sufficiently symmetric and homogeneous universes, the gravitational interaction of massive objects with distant matter leads to an acceleration-dependent force, i.e., inertia.

James F. Woodward [3,4] extended Sciama's calculations by introducing energy flow (e.g., the energy flowing to a charging capacitor) into the gravitating system. He demonstrated that the equations acquire extra transient contributions in Sciama's inertia term that are proportional to 1/G (Newton's gravitational constant) and therefore are quite large. The implications of this work are: (a) that it may be possible to modify inertia, and (b) that it may be possible to demonstrate the validity of Mach's Principle with a tabletop experiment.

Woodward and his students [4-7] have attempted to observe the predicted inertia-variation effect by accelerating a mass-varying object so that it produces a reactionless force. To illustrate this, assume that an inertia-varying test mass is accelerated to the right when it has low inertia and to the left when it has high inertia. In this circumstance, it is argued, the reaction forces of the two accelerations are unequal and one might expect the net reactionless force to "row" the system to the right. Woodward's group reports [7] using a sensitive torsion balance to observed small reactionless forces at magnitudes that are near the limits of their sensitivity and about five orders of

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magnitude smaller than the predicted effect (see the calculations below.)

Unfortunately, this scheme for observing the predicted inertia variation appears to be at odds with the relativistically invariant form of Newton's 2nd law of motion:

$$\vec{F} = d\vec{p}/dt = m\, d\vec{v}/dt + \vec{v}\, dm/dt \qquad (1)$$

Since the inertial mass **m** of the test body is expected to vary with time, the last term of Eqn. (1) cannot be ignored. It is not surprising, in view of Newton's 3rd law of motion, that for any closed cycle of acceleration and variation of the inertial mass around a central value, the force contribution from the **v dm/dt** term is found to precisely cancel the supposed "reactionless force" arising from the **m dv/dt** term, leading to a net force of zero for the overall system.

From this simple calculation, it appears that reactionless force searches are ***not*** good tests of the proposed effect. There remains the question of whether the Woodward inertia variation is indeed present in a system with energy flow. We have found, as will be described below, that a mechanical oscillator, driven at resonance, with its mass programmed to vary at the drive frequency, shows sensitive variations in drive-to-response phase and amplitude, depending on the relative phase between the mass variation and the oscillator drive.

Theory

Woodward has shown [5] that the relativistically invariant wave equation, in the simplest approximation and expressed as a function of an overall scalar gravitational potential ϕ, has the form:

$$\nabla.\phi - (1/c^2)(\partial^2\phi/\partial t^2) = \quad \phi = 4\pi G\rho_o + (\phi/\rho_o c^2)(\partial^2\rho_o/\partial t^2) - (\phi/\rho_o c^2)^2(\partial\rho_o/\partial t)^2 \qquad (2)$$

where G is Newton's gravitational constant, ρ_o the rest mass density, and c the speed of light. This field equation is obtained only if one assumes, as suggested by Mach's Principle, that the local energy density of matter is equal to the matter density times ϕ. Since Mach's Principle demands that $\phi = c^2$ when measured locally, this constraint is equivalent to asserting that $E = mc^2$. Additional terms would be present in this equation were it not for the fact that, as a consequence of Mach's principle in this approximation, $\phi = c^2$.

In writing Eqn. (2), Woodward neglects a term of the form $c^{-4}(\partial\phi/\partial t)^2$ because it is always small, given its c^{-4} coefficient that is not compensated for by any factor of ϕ in the numerator. Combining the last three terms of Eqn. (2) into an effective mass density $\rho(t)$ and solving for this quantity gives the time-dependent effective mass density as:

$$\rho(t) \approx \rho_o + (1/4\pi G)[(\phi/\rho_o c^2)(\partial^2\rho_o/\partial t^2)] - (1/4\pi G)[(\phi/\rho_o c^2)^2(\partial\rho_o/\partial t)^2]. \qquad (3)$$

The second term in Eqn. (3) has the form $(1/4\pi G)[(\phi/\rho_o c^2)(\partial^2\rho_o/\partial t^2)]$. This time-dependent fluctuation in the inertial mass can be both positive and negative when ρ_o undergoes periodic time variations, e.g., when a varying flow of mass-energy is present. This is the inertia-varying term of interest.

In the present work we will ignore the last time-dependent or “wormhole” term, which has the form $-(1/4\pi G)[(\phi/\rho_o c^2)^2(\partial\rho_o/\partial t)^2]$. This mass term is always negative or zero and for sinusoidal variations is about 0.1% or less of the other terms.

If a capacitance **C** is driven by a voltage source with time dependent potential $V(t) = V_0 Sin(\omega t)$, then the energy in the capacitor, assuming dissipative and inductive effects can be neglected, is $U(t) = ½C\, V(t)^2 = ½C\, V_0^2 Sin^2(wt)$. The second time derivative of this stored energy divided by c^2 (to convert it to a mass) is $d^2U/dt^2 = C\, V_0^2\, \omega^2\, Cos(2\omega t)/c^2$. This is the $(\partial^2\rho_o/\partial t^2)$ factor in Woodward's Eqn. (3). The corresponding time dependent variation in inertial mass, assuming that $\phi = c^2$, is then:

$$dm(t) = 1/(4\pi\rho_o G\, c^2)\, C\, V_0^2\, \omega^2\, Cos(2\omega t). \qquad (4)$$

We will use this form for the variation in inertial mass in the analysis that follows.

To give this prediction a scale, let us assume that $c = 2.998\times10^8$ m/s, $G = 6.672\times10^{-11}$ m^3/kg s^2, $\rho_0 = 2{,}000$ kg/m^3, $C = 9.3\times10^{-9}$ F, $V_0 = 2{,}000$ V, and $\omega = 2\pi\times1{,}000$ Hz. With these values, we find that:

$$dm(t) = 9.7\ mg \times Cos(2\pi\times2{,}000\ Hz\times t). \qquad (5)$$

In other words, under these conditions, which should be realizable in the experiment described here, the inertial mass of the capacitance is predicted to vary by about ±10 milligrams at *twice* the capacitor charging frequency, or 2,000 Hz. If the mass of the capacitor and its holder were about 1 g, this would represent a mass variation of about ±1%. Such a mass variation would have large observable consequences. However, we note that Woodward [4] has made arguments involving mobile charges to explain why the actual variation in the inertial mass may be orders of magnitude smaller than that predicted by simple calculations and more consistent with his reported observation of very small reactionless forces.

It is also of interest to consider the maximum current flow that is necessary to charge the capacitor in the manner assumed above. The charge on the capacitor is $\mathbf{q=C\ V(t)}$, so the charging current is $\mathbf{i(t) =C\ dV/dt = C\ V_0\ \omega Cos(\omega t) = 116\ mA \times Cos(\omega t)}$ for the specified conditions. It turns out that a high voltage power supply/amplifier capable of delivering an audio-frequency peak current of a few hundred milliamps at a few kilovolts is very expensive (~$14,000) and represent the most costly component required for the present test of the Woodward effect.

A Driven Mass-Varying Oscillator

We test for the presence of the Woodward effect by using the capacitor as the mass in a system that forms a driven mechanical mass-and-spring oscillator with an undriven resonant frequency of $\boldsymbol{\omega_0}$. Such an oscillator is shown schematically in Fig. 1

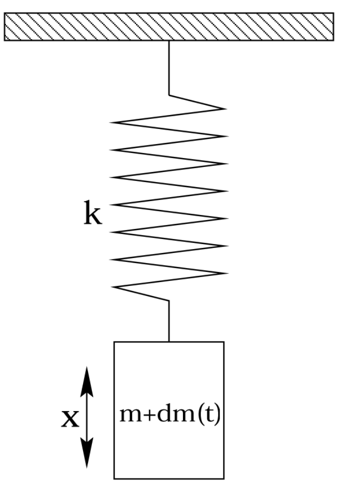

Figure 1. Schematic mass-and-spring mechanical oscillator with time varying mass **m+dm(t)** and restoring-force spring constant **k**. The system is assumed to have a dissipative damping force of $\mathbf{-b\ dx/dt}$.

The oscillator is driven at its resonant frequency $\boldsymbol{\omega_d=(\omega_0^2 - b/2m)^{1/2}}$ with a voice coil actuator and audio amplifier. At the same time, we charge the capacitor sinusoidally, using approximately the parameters specified above, at a frequency of $\boldsymbol{\omega_d/2}$ so that, in the presence of the Woodward effect, the capacitor's inertial mass should vary at frequency $\boldsymbol{\omega_d}$.

The inhomogeneous non-linear differential equation describing such a system is:

$$\begin{aligned} F_d Cos[\omega_d t] = kx(t) + [b + \mu'(t)]\,x'(t) \\ + [m + \mu(t)]x''(t), \end{aligned} \quad (6)$$

where **x(t)** is the motion of the capacitor, $\mathbf{F_d}$ is the magnitude of the driving force, $\boldsymbol{\omega_d}$ is the angular frequency of the driving force, **k** is the Hooke's law restoring force constant, **b** is the damping constant representing dissipative forces in the system, **m** is the average mass of the capacitor and associated structure, and $\boldsymbol{\mu(t)}$ is the time-dependent mass variation due to the Woodward effect. Note that the $\boldsymbol{\mu'(t)x'(t)}$ term in Eqn. (6) arises from the **v dm/dt** term in Eqn. (1).

We can replace the spring constant **k** with $\boldsymbol{m\ \omega_0^2}$ and replace $\boldsymbol{\mu(t)}$ with $\boldsymbol{\mu_0 Cos(\omega_d t + \phi_m)}$, which assumes that we have arranged the mass variation to be at the same frequency as the driving force but shifted in phase by $\boldsymbol{\phi_m}$. With these substitutions, Eqn. (6) becomes:

$$\begin{aligned} F_d Cos(\omega_d t) &= m\omega_0{}^2 x(t) \\ &+ [b - \mu_0 \omega_d Sin(\omega_d t + \varphi_m)]\,x'(t) \\ &+ [m + \mu_0 Cos(\omega_d t + \varphi_m)]x''(t) \end{aligned} \quad (7)$$

This non-linear differential equation has no analytic solutions and must be solved numerically. Fig. 2 shows the results of such numerical solutions of Eqn. (7), assuming that $\mathbf{F_d/m}$=0.01, **b/m**=0.01, and $\boldsymbol{\mu_0}$**/m**=0.001. The latter assumption represents only about 10% of the predicted 10 mg mass variation.

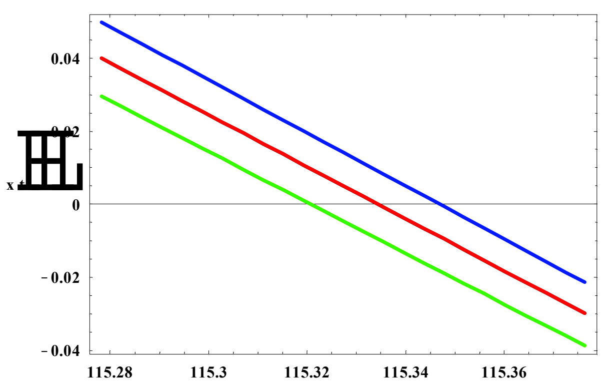

Figure 2. Response phase shifts of the system to variable mass. The central line is the system response with μ_0=0. The other two lines represent μ_0=0.001 with $\phi_m= -\pi/2$ (low), and $\phi_m=+\pi/2$ (high). The phase shifts shown are about ±0.04 radians=±2.3 degrees.

We find that when the mass variation has a relative phase of $\pm\pi/2$ with respect to the driving force, it causes a positive or negative phase shift in the response motion by shifts, using the values listed above, of several degrees. Other phases near 0 or π can cause an increase or decrease in the amplitude of oscillation. The experiment we have constructed is designed in an attempt to observe these phase-shift effects.

Experimental Apparatus

Fig. 2 below shows a top view of the mechanical oscillator arrangement, which we call the "Mach Guitar". The barium titanate capacitor test mass is suspended between pairs of tensioned wires, with the tension adjusted so that the resonant vibration frequency for vertical oscillations is about 1-2 kHz.

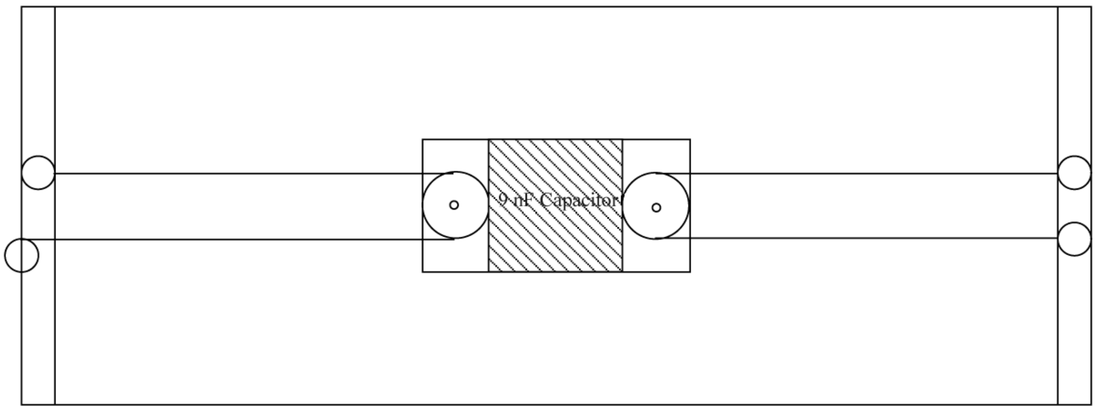

Figure 2 Top view of "Mach Guitar" arrangement. The capacitor is suspended between pairs of tensioned wires that provide the restoring force for the mechanical oscillator. Capacitor drive voltage is supplied through the wires.

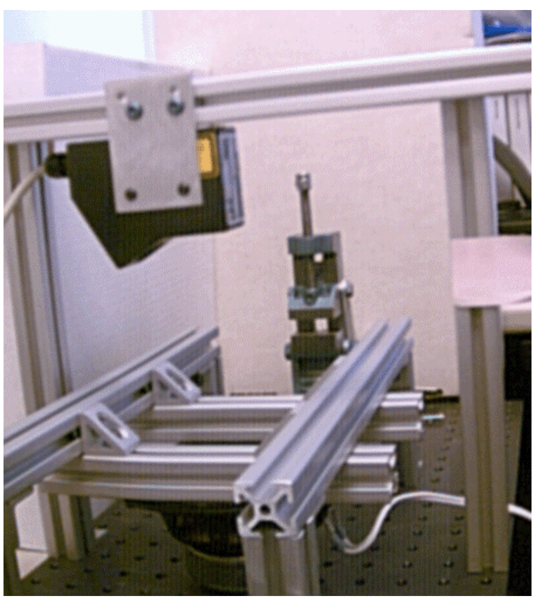

Figure 3 Laser-optics table with oscillator removed, showing voice-coil drive (below) and laser position monitor (above).

Electrical connections for the capacitor drive voltage are supplied through the tensioned wire pairs. The capacitor and its support structure have a net mass of about 1 g.

The restoring force provided by the tensioned wire pairs is $\mathbf{F=-(8T/L)x}$, where $\mathbf{T}$ is the tension in a given wire, $\mathbf{L}$ is the overall length, from bridge to bridge, of the system, and $\mathbf{x}$ is the vertical displacement of the capacitor. Therefore, neglecting the mass of the wire, the resonant frequency of the oscillator is $\boldsymbol{\omega_0=(8T/mL)^{1/2}}$. If $\mathbf{m}$=1 g, $\mathbf{L}$=0.5 m and $\boldsymbol{\omega_0}=2\pi \times 1000$ Hz, then the required tension is 553 lb. This tension can be reached with 13 gauge steel wire.

Fig. 3 shows a view of the laser-optics table (with oscillator removed) that is the foundation of the experiment. A pre-drilled aluminum laser-optics base plate supports the general-purpose aluminum beam structures, on which are mounted (below) the voice-coil drive (a modified audio speaker) for the mechanical oscillator, and (above) the laser position-measuring device shown in Fig. 4.

The Mach Guitar is mounted on the laser-optics base, which provides "bridges" to support for the wires and their tensioning mechanism. Electrical connections to the capacitance are made through the support wires. Below the oscillator is an audio speaker, which drives the oscillator through a light spring. Above the oscillator is a commercial laser position detector, which measures the vertical position of the capacitor's upper surface by electronic triangulation. The laser position sensor is shown in Fig. 4

Fig. 4 Laser position measurement device.

The mass-varying object used in the measurements is a low-loss and low-mechanical-movement barium titanate capacitor with a capacitance of about 9 nF and a voltage rating of 3 kV. This oscillator mass is suspended between pairs of 13 gauge steel wires (0.25 m long on each side) that have been tensioned to about 500 lb to provide a system resonant frequency of about 1000 Hz.

Fig. 5 Trek Model PO923A HV Power Amplifier, used for driving the capacitor at 2 kV and 400 mA.

As previously mentioned, the most challenging problem presented by the present experiment is driving the capacitor to high voltages at audio frequencies. The reason is that all high-voltage amplifiers driving capacitive loads are severely limited by the charging current that they must deliver. We have selected a Trek Model PO923A High Voltage Power Amplifier, shown in Fig. 5, as the capacitor driver. It can drive at voltages up to 2 kV with a peak charging current of up to 400 mA.

The Mach's Principle test employs a Pentium-2 850 MHz computer system with a Windows 98 operating system for experiment control, using control software based on LabView. It consists .of controls for the mechanical oscillator driver and the capacitance driver, a data collection system that records the drive signal and the position measurements, a data recording and retrieval system, and analysis software for processing the data and extracting the phase information of interest.

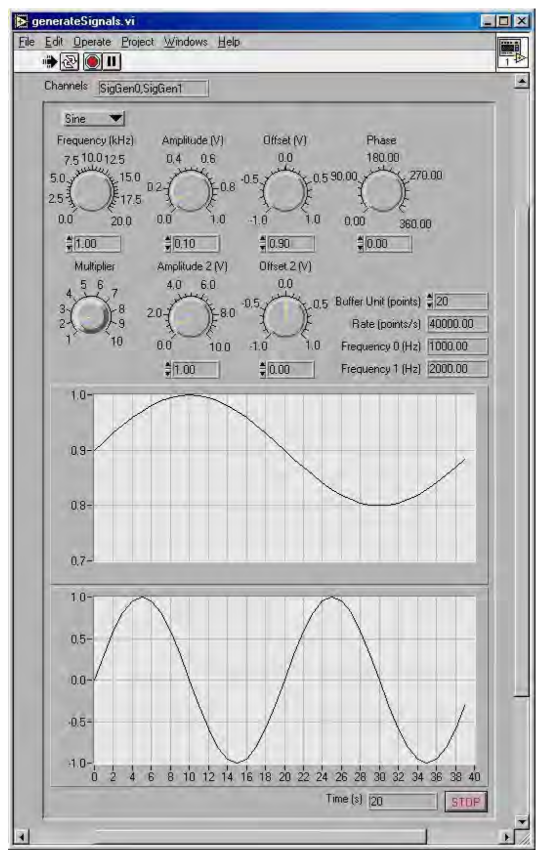

Figure 6. LabView control panel and display for system drivers.

The LabView control panel and display for the experiment is shown in Fig. 6 above. The system generates sine waves with adjustable phases and amplitudes at two frequencies, normally set to differ by a factor of two. The low frequency signal provides the input to the high voltage amplifier that drives the capacitor. The high frequency provides input to an audio amplifier connected to a voice coil that drives the mechanical oscillator.

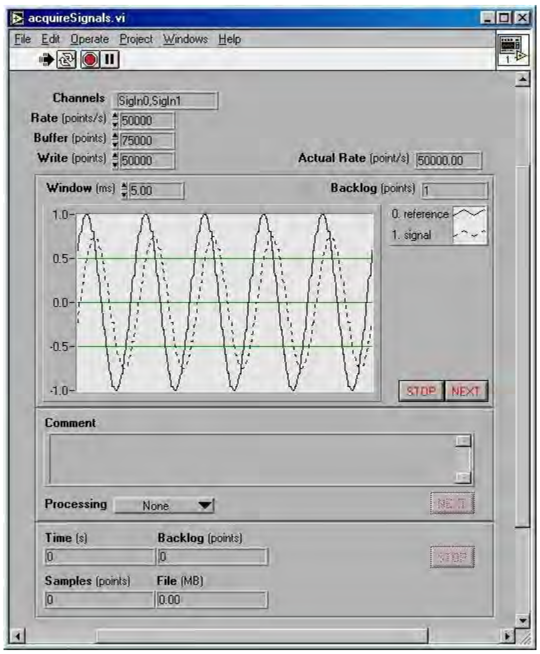

Figure 7. LabView data acquisition and display.

Figure 7 shows the LabView panel for the data collection system. The system samples the mechanical drive voltage and the capacitor position measurement of the mechanical oscillator as separate data streams. These are sampled for real-time display and also recorded on the system hard disk. These data streams can be read back and re-analyzed. The data are analyzed by integration over a long time period to extract the relative phase of the drive and response signals for a given setting of the capacitor drive phase with respect to the mechanical driver.

The processed quantity that will be accumulated in the analysis is the cosine of the relative phase between the driving signal **D(t)** and the mechanical response signal **R(t)**. There are a variety of ways of extracting this signal, but the one we will use initially is:

$$Cos(\varphi) = \frac{\int_0^T [D(t)+R(t)]^2\,dt - \int_0^T [D(t)-R(t)]^2\,dt}{4\sqrt{\int_0^T D(t)^2\,dt \times \int_0^T R(t)^2\,dt}} \qquad (8)$$

Here **T** is an arbitrary integration time that increases as data is collected and the running integrals are accumulated. The values of **Cos(ϕ)**, which is near 0 because ϕ is approximately **π/2** on resonance, will be compared for the two most extreme settings of the phase of the capacitor drive, which should produce phase shifts like those shown in Fig. 2. We estimate that with a data collection cycle of a few hours, **Cos(ϕ)** can be determined to an accuracy of a few parts in 10^5. This should enable us to determine the shift in ϕ to similar accuracy, providing a fairly stringent test of the presence or absence of the Woodward mass variation.

Experiment Status

The experiment is presently being reconfigured on the laser-optic table. The initial cantilever arrangement is being replaced with the new "Mach guitar" mechanical oscillator system described above.

The previous mechanical oscillator, which used a capacitor mass suspended at the free end of an aluminum cantilever, was tested and found to present three serious problems for the experiment: (1) its resonant frequency was fixed by the length and mass of the cantilever and was not easily adjustable, (2) The cantilever mass dominated that of the capacitor, greatly reducing the magnitude of the predicted effect and (3) it was not capable of achieving resonant frequencies above a few hundred Hz. Since the size of the predicted mass-variation effect increases as ω_0^2, this was a serious limitation. However, initial experience with this cantilever oscillator provided valuable experience in operating and testing the position measuring device and the data collection system.

The new Mach Guitar oscillator provides significant improvements over the cantilever in reduced mass and increased operating frequencies, and it offers the additional advantage that it is easily tunable through simple adjustments of the wire tension.

We expect to begin data collection with the new configuration in the next few weeks.

Conclusion

The test of Mach's principle and the Woodward effect described above is not yet completed, but it shows promise of providing an independent test of the predictions that does not depend on the possibility of a reactionless force. The experiment in the present configuration is not as sensitive as the torsion-balance measurements recently reported by Woodward [7]. However, since it is not based on a reactionless force, it may not need that sensitivity.

If the Woodward Effect is observed, it will have important implications for general relativity and cosmology, for validating Mach's Principle, for control of inertia, and possibly for propulsion. If the Woodward Effect is not observed at the sensitivity limit of the experiment, this will also be worth knowing.

Acknowledgements

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SUPERLUMINAL BUT CAUSAL WAVE PROPAGATION

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Abstract: A series of experiments in recent years have shown that under carefully designed circumstances the group velocity, or even more surprisingly the energy velocity can exceed the speed of light in vacuum or become negative (abnormal velocities). These abnormal results have led some researchers to question the validity of special relativity, or at least cast doubt on the relevance of these principles to the aforementioned experiments. In this work series of experiments with single electromagnetic pulses measured in both time and frequency domain are described. It is seen that while these experiments verify the aforementioned abnormal velocities, they are not in contradiction with the principles of special relativity (Einstein causality). In this regard, the important concept of "front" or "Sommerfeld forerunner" is reintroduced, and it is argued that the only physical velocity required to obey the Einstein causality is the "front velocity."

I. Introduction

The fact that the group velocity of an electromagnetic wave packet (pulse) can exceed the speed of light in vacuum (become superluminal) has been demonstrated in many experiments using single photons [1, 2], at optical frequencies [3], and using microwaves [4-10]. As a starting point, an interested reader may consult the review by Chiao and the references therein [11]. Despite one's initial impression, the superluminal group or even energy velocities (defined as the ratio of the Poynting vector to the stored electromagnetic energy) are not at odds with the requirements of relativistic causality (Einstein causality), and indeed it can be shown that they must exist as the natural consequence of the Kramers-Kronig relations, which in themselves are a statement of the system linearity and causality [12-15].

The point that in the regions of anomalous dispersion, group velocity can become superluminal was first considered by Sommerfeld and his student Brillouin [16]. In their studies, they examined a sinusoidally modulated step-function propagating through a medium with Lorentzian dispersion. They identified five different velocities: phase, group, energy, Sommerfeld forerunner ("front†") and Brillouin forerunner velocities‡. However, with the passage of time, and for reasons unknown to the authors, while the first three velocity terms have received much attention in both undergraduate and graduate books, the latter two have not enjoyed the same status. This is even more surprising since, among the above velocities, it is only the

† To be more rigorous the term "front" refers to the onset of Sommerfeld forerunner propagation.
‡ To be complete one has to add the term "signal velocity" defined as the velocity of the half maximum point to the list. However, by their own admission such a definition is arbitrary [16] and as discussed in Ref. (4) can become superluminal.

velocity of the "front" that must satisfy the requirements of Einstein causality under all circumstances. In other words, it is rather a naïve understanding of Einstein causality to equate the group velocity with the velocity of information transfer under all circumstances, particularly when one is concerned with the propagation of "attenuated traveling waves[§]."

Our objective here is to discuss the phenomenon of superluminal and negative group and energy velocities which generically is referred to as the abnormal velocities. In Sec. II a time-domain experiment used to detect the superluminal group velocities in the case of a one dimensional photonic crystal (1DPC) is described. Section III discusses a frequency-domain experiment used to demonstrate the same superluminal phenomenon. The case of superluminal or negative group and energy velocities for an inverted medium (medium with gain) or in the case of medium with negative index of refraction is considered in Sec. IV. Section V is intended to put the reader's mind at ease by providing some general arguments on why the abnormal velocities discussed in the previous sections are not in contradiction with the requirements of special relativity. Section VI is our condensed attempt is addressing the issue of superluminality in the limit of very weak light (very few photons). Our final remarks and a discussion for the general public can be found in Sec. VII.

II. Time-domain Experiment

Consider the problem of electromagnetic wave propagation through a periodic structure. Figure 1 shows an experimental setup used to detect the superluminal group velocity for a microwave wave packet tunneling through a 1DPC. A backward wave oscillator (BWO) was used to generate the pulse, and a mode converter (MC) was used to convert the TM_{01} mode of the BWO to a TE_{11}. The pulse was then radiated via a conical horn

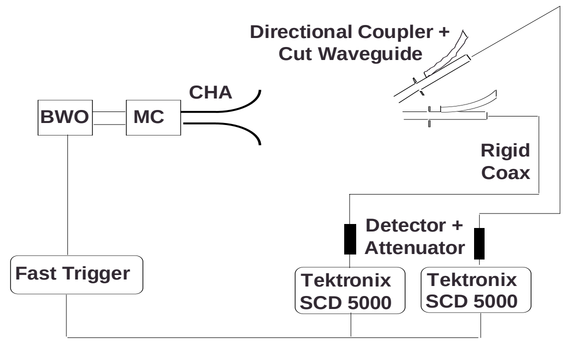

Fig. 1: Time-domain experimental setup

antenna (CHA). The frequency output of the source was tuned to the mid-gap frequency of the 1DPC at 9.68 GHz (FWHM of 100 MHz) and was detected by two HP 8470-B, Schottky diode detector (provided in pairs). The CHA radiation intensity was sampled along two distinct directions (paths), referred to as "side" and "center". A series of microwave pulses were fired in order to measure and then remove the time difference between the two paths due to the differences in cable lengths, internal detection of the oscilloscopes (Tektronix SCD 5000) and other incompatibilities. This measured time difference was electronically compensated such that the peaks corresponding to the pulses traveling through the "center" path and "side" path in the absence of the 1DPC arrived at the same time. At this point, the 1DPC was inserted along the "center" path and series of single pulse were fired. Figure 2 shows the result. It is seen that the peak of the wave packet propagating along the "center" path and tunneling through the 1DPC arrives (440 ± 20) ps earlier than the accompanying pulse propagating through free-space along the "side" path. This

§ We have used the term "attenuated traveling waves" in the same sense as in Ref. (17), although, sometimes the term evanescent is used to signify the same thing.

advancement in time for the tunneling pulse can easily be translated to a measure of the pulse group velocity, indicating that the tunneling wave packet propagated with a

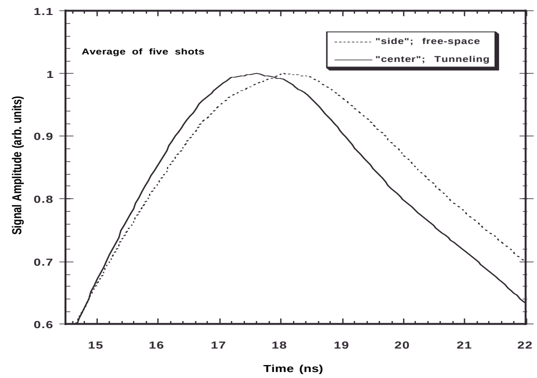

Fig. 2: Superluminal propagation for the tunneling pulse

group velocity $(2.38 \pm 0.15)\,c$.

Furthermore, the traditional view of pulse propagation through a region with high attenuation (regions of anomalous dispersion) held that the extreme

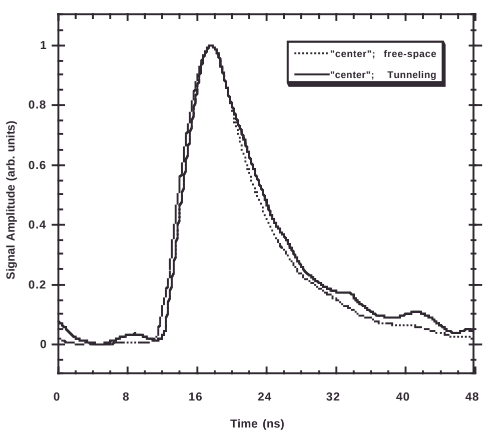

Fig. 3: A measure of the pulse broadening due to tunneling through the 1DPC. The two pulses have propagated along the same path ("center"); one in the free-space and the other through the 1DPC.

attenuation, coupled with the dispersion, would distort the signal to such an extent that the originally well defined wave packet and its peak would not be recognizable upon the emergence from such a medium [17 16]. Figure 3 shows that in contrast to this common belief, the tunneling wave packet of Fig. (2) suffered minimal dispersion such that the FWHM of the pulse after tunneling was only increased by 1.5%. In obtaining this figure the tunneling wave packet was manually moved to later times as to make the comparison between the two pulses easier. A full description of the above experiment can be found in Ref. (4).

III. Frequency-Domain Experiment

In the last section the feasibility of measuring superluminal group velocities directly in time-domain was discussed. This abnormal behavior can also be demonstrated in frequency-domain. Figure 4 shows the

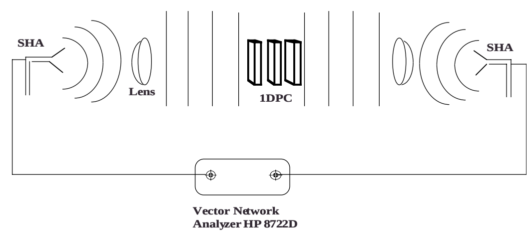

Fig. 4: Frequency-domain experimental setup

free-space setup used to detect the superluminal group velocities in frequency-domain. The setup consists of two K-band standard horn antennas (SHA) configured a transmitter and receiver and connected to ports 1 and 2 of an HP 8722D vector network analyzer (VNA). The radiated quasi continuous waves are collimated using two microwave lenses and the setup is enclosed in a anechoic chamber to reduce stray signals.

The essence of the approach is to measure *accurately* and *reliably* the transmission phase associated with the 1DPC. Once this quantity is measured, the group delay (τ_g) and group velocity (V_g) can be calculated according to

$$\tau_g = -\partial\,\phi / \partial\,\omega, \qquad (1)$$

$$\frac{v_g}{c} = \frac{L_{pc}}{c\,\tau_g} = \frac{-L_{pc}}{c\left(\partial\phi/\partial\omega\right)}, \qquad (2)$$

where ϕ is the transmission phase, and L_{pc} is the physical length of the 1DPC.

Fortunately, recent advances in non-coaxial (free-space) calibration techniques for VNA such as the "Thru-Line-Reflect" (TRL), [18, 19] make it possible to measured the transmission coefficient accurately and reliably. After calibrating the system (without the 1DPC), a reference plane of unit magnitude for transmission magnitude and zero phase for ϕ is established midway between the two SHAs. At this point, the 1DPC is inserted and the receiver horn is moved back exactly by a length equal to the thickness of the 1DPC (L_{pc}).

Figure 5 is the calculated (solid line)

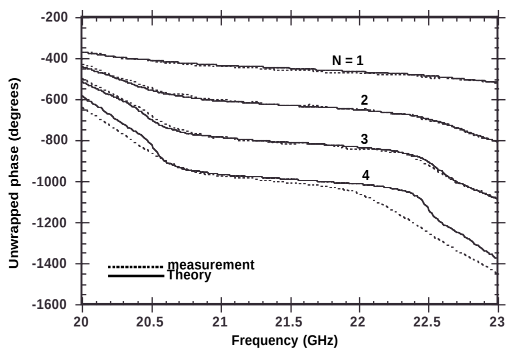

Fig 5: The unwrapped transmission phase for the 1DPC with various number of Eccostock® dielectric slabs.

and measured (dotted line) unwrapped phase for a 1DPC with four, three, two and one dielectric slabs (the spacer is always air). The theoretical calculations are based on the diagonalization of one period matrix, and is presented in Ref. (5).

According to Eqs. (1) and (2), to ascertain the group delay and group velocity the data presented in Fig. 5 must be differentiated. However, differentiating a noisy data amplifies the noise and may lead to spurious effects. To avoid the arbitrariness associated with smoothing, a best nonlinear least square fit of the experimental phase data is obtained. The parameters used in fitting the experimental data all match the actual variables very well and for the sake of brevity are not given here, but can be found in Ref. (5).

Figure 6 shows the result of the least square fit to the phase data of Fig. 5 together

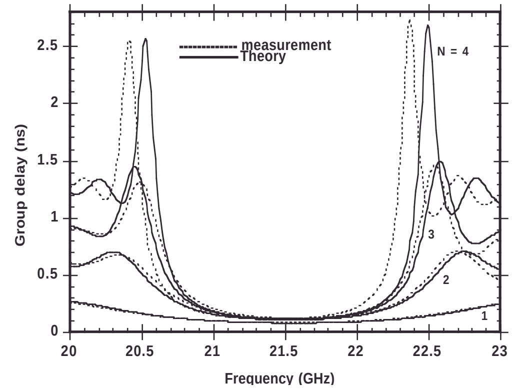

Fig. 6: Measured and calculated group delay for the 1DPC. The parameters used to obtain the fitted curves (measurement) and the calculated curves (theory) are given in Ref (5).

with Eq. (1), in order to determine the group delay in a 1DPC with one, two, three, and four dielectric slabs. Consequently, the normalized group velocity given by Eq. (2)

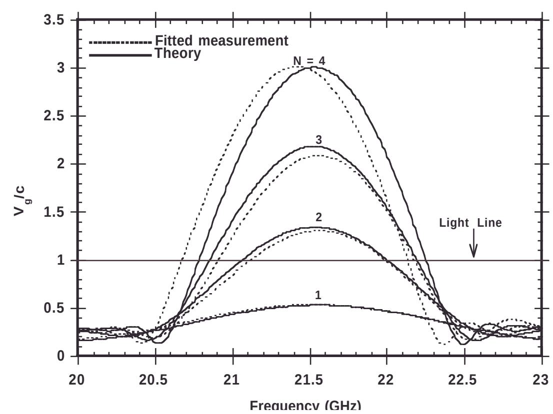

Fig. 7. Normalized group velocity for the 1DPC. The dotted curves are the measured results obtained from the fitted curves in Fig. 6 and Eq. 2. The solid curves are theoretically calculated.

can be obtained from the Fig. 6 and is shown in Fig. 7. Along with the velocities derived from the fit (dotted curves), the theoretical group velocities calculated from the measured values of thicknesses and indices are also shown (solid curves). As Fig. 7 indicates, in the case of $N=4$ and $N=3$, a maximum superluminal group velocities 3 and 2.1 times c is observed. The results depicted in this figure cab be interpreted as the following. If one is to construct a pulse entirely composed of the frequency components for which the superluminal behavior is predicted, then the pulse is expected to propagate with group velocity exceeding c, similar to the situation discussed in the Sec. II.

IV. Abnormal Velocities in Inverted Medium and Medium with Negative Index

The circumstances under which the group or even energy velocity are abnormal are not limited to the evanescent wave propagation discussed so far. In this section three situations are described which exhibit the aforementioned abnormal behavior.

First, for an inverted medium (medium with gain) described by a Lorentz-Lorenz dispersion, the index of refraction is given by

$$n(\omega) = \left(1 - \frac{\omega_p^2}{\omega_0^2 - \omega^2 - i\gamma\omega}\right)^{1/2} \qquad (3)$$

where ω_0 is the resonance frequency, γ is a small damping factor, and ω_p is the effective plasma frequency. Note that a negative sign precedes the second term under the square root due to the population inversion of the medium. A plot of the index of refraction for both the inverted and non-inverted medium is shown in Fig. 8. From the figure it is clear that for an inverted medium, in the limit of very low frequencies, the index is less than one implying that the phase velocity is superluminal. More importantly, at the low frequencies, the group velocity given by

$$V_g(0) = \frac{c}{\left[n(\omega) + \omega\, dn/d\omega\right]_{\omega\to 0}} = \frac{c}{n(0)} = V_p(0) > c \qquad (4)$$

is also superluminal. Under these circumstances the energy velocity (V_e), given by the ratio of Poynting vector (S), to the stored energy density (u), is also equal to the phase and group velocity and exceeds the speed of light in vacuum.

$$V_e = \frac{S}{u} = \frac{c}{n(0)} = V_p(0) > c \qquad (5)$$

The equivalence of the above three

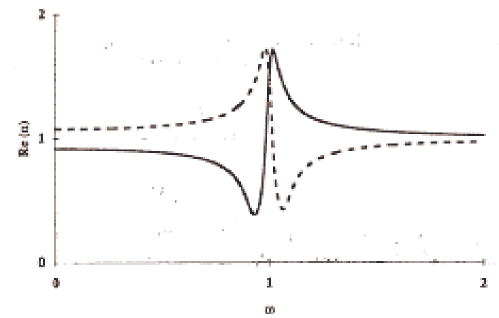

Fig. 8: The real part of the index of refraction for an inverted medium (solid curve) and non-inverted medium (dashed curve.)

velocities is merely a statement of the fact that in the limit of low frequencies the medium is transparent and dispersionless [13].

Second, it is also possible to observe

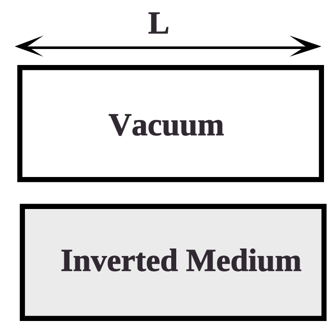

Fig. 9: Two cells of equal length containing inverted medium and vacuum.

negative group velocities for electromagnetic (EM) pulses tuned slightly away from a gain line of an inverted medium. [14, 20-22]. The physical meaning of a negative group velocity can be explained as the following. Consider two cells of physical length L containing an inverted medium and vacuum as shown in Fig. 9.

The time difference between two well behaved identical EM pulses propagating through the lower (inverted) and the upper cell (vacuum) is given by

$$\Delta t = \tau_g - t_{vac} = \frac{L}{V_g} - \frac{L}{c} = \frac{L}{c}\left(n_g - 1\right) \quad (6)$$

where n_g is the group index. From the above equation it is clear that if the group index is zero the time difference between the two pulses is given by the negative of L/c In other words, when one of the EM pulses is at the exit face of the lower cell the other pulse is about to enter the upper vacuum cell. Stating this point differently, if one only consider a single cell containing the inverted medium, for a negative group index, the peak of the transmitted wave packet leaves the cell prior to the peak of the incoming wave packet entering the medium. It must be pointed out that as shown by Landauer [23-25] it is naïve to regard the peak of the outgoing pulse as the causal response of the medium to the peak of the incident pulse. The theoretical prediction by one of us [22] regarding the feasibility of detecting negative group velocity was recently verified in an experiment by Wang [26] in which the inverted medium was a cell containing Cesium vapor.

Finally, let us consider a situation for which the medium effective index is a negative value. A point worth emphasizing is the fact that for these media it is the effective index and not the actual material index which is negative. In other words, the wavelength of the incident wave is many times larger than the physical size of the components comprising the media, allowing one to characterize the over all response of the media in terms of an effective index.

The first theoretical work in this area was done by Veselago [27, 28], and the more recent interest in the subject was reignited by the work of Pendry [29, 30] and Smith et. al. [31, 32], which demonstrated the possibility of manufacturing these media at microwave frequencies. Figure 10, shows the dispersion relation for a negative index

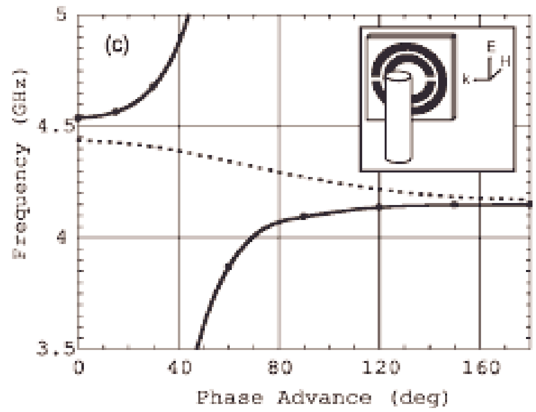

Fig. 10: The dispersion curves for a medium with negative effective index

medium, borrowed from Ref. (32). From the figure it is clear that for a certain frequency range, the derivative of the curve depicted in Fig. 10, (i.e. the group velocity) is negative. Even more surprising is the fact that the energy velocity, given by Eq. (7), is also negative, since in these media both permittivity and permeability are negative parameters.

$$V_e \propto \frac{\vec{E} \times \vec{H}}{\varepsilon \left|\vec{E}\right|^2 + \mu \left|\vec{H}\right|^2} \quad (7)$$

The presence of negative group and energy velocities for the above media can be understood in the following manner. The

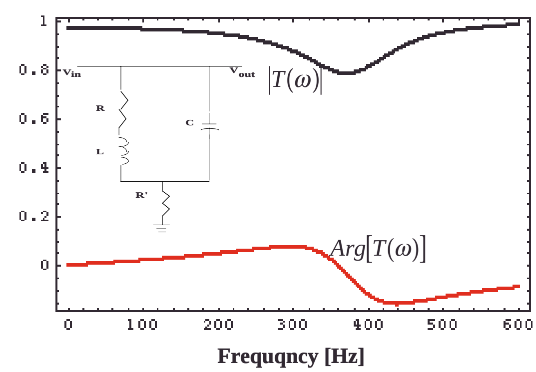

Fig. 11: Transmission magnitude and phase for the LRC circuit shown in the inset.

negative index medium, considered by Smith et. al. [31], is in essence a distributed

LRC transmission line that its response can be approximated by a lumped LRC circuit. The inset in Fig. 11 is a typical LRC circuit that exhibits negative group delay in the region of maximum attenuation[**]. Once again, if one is to construct an EM pulse mostly composed of frequency components having negative group delays, it is expected that the group and energy velocities for this EM pulse to be negative. We currently are pursuing the detection of the aforementioned abnormal velocities in the negative index media. We end this section by pointing out that in addition to negative velocities, the negative index medium has many other interesting properties such as inverted Doppler shift, Cherenkov radiation, and Snell's law.

V. Superluminal Velocities and Einstein Causality

In so far we have discussed situations for which the phase, group, and energy velocities are abnormal (superluminal or negative). The reader may began to wonder whether or not these abnormal velocities are in contradiction with the requirements of relativistic causality. The short answer to this question is that under no circumstances the so called "front velocity" may exceed the speed of light in vacuum, and in fact under all circumstances the "front velocity" is exactly luminal. In other words, the requirement of Einstein causality that no "signal" (information) can be transmitted superluminally is satisfied in all cases, since the "front velocity' is always luminal. This means that the presence of the genuine information should not be associated with the pulse maximum, half maximum, or the envelope, but indeed is contained within the singularities (points of non-analyticity) of the pulse. Because of the important role played by the "front" in satisfying the requirements of special relativity, let us briefly discuss some of the most general ideas associated with this concept. The interested reader may consult the Ref. (4) for more detailed analysis.

The essential point to remember is the fact that any *physically realizable* signal is restrictively time-limited. In other words, any electromagnetic signal created and later propagated through free-space or a 1DPC must be generated at a point in time and space. One can then always point to a time prior to which the signal did not exist. This point in time, or more precisely the transient "turn on times," are points of non-analyticity for which the amplitude of the pulse or its first or higher derivative are discontinuous.

The importance of these points of non-analyticity becomes clear when considering the following. While the future behavior of a truly analytical signal such as a Gaussian wave packet can be completely predicted by means such as a Taylor expansion (or a Laurent expansion for functions that are holomorphic in an annular region), the presence or arrival of the singularities do not yield themselves to such an extrapolation. Moreover, as discussed in the above, no *physically realizable* signal can be presented by an *entire function*[††] hence, any communication of information must involve the transmission of the "front". To summarize, there is no more information in a pulse peak or envelope that is not already contained within the earliest parts of the signal.

The mathematical proof that no signal (information) may be detected sooner than $t_0 = x/c$ can be seen via contour integration of an expression such as Eq. (8). Equation (8) describes the field at the position x and time t for a wave packet

[**] In obtaining Fig. 11, in contrast to the curves depicted in Fig. 5, a time dependency of $e^{-i\omega t}$ in place of $e^{j\omega t}$ was used. In other word, the group delay has the opposite sign of that shown in Eq. (1).

[††] An *entire function* is the one that is analytical everywhere in the complex domain.

impinging at normal incident on a medium characterized by an index of refraction, n, [33].

$$u(x,t) = \int_{-\infty}^{+\infty} \frac{2}{1+n(\omega)} A(\omega)\, e^{i k(\omega) x - i\omega t}\, d\omega, \quad (8)$$

$$A(\omega) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} u(x=0,t)\; e^{i\omega t}\, d\omega. \quad (9)$$

Transforming the integral in Eq. (8) into the complex domain and closing the contour over the upper-half-plan, along with requiring that the medium characterized by n to be causal, and that the incident wave packet has a "front," are sufficient conditions to show that the value of the integral is identically zero for $t \le t_0 = x/c$ or equally for velocities, $V = x/t > c$. The condition that the medium characterized by n is causal, means that for this medium the effect can not proceed the cause. Mathematically this is expressed as $G(\tau) = 0$ for $\tau < 0$, where $G(\tau)$ is the susceptibility kernel given by

$$G(\tau) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \left[\varepsilon(\omega)/\varepsilon_0 - 1\right] e^{-i\omega\tau}\, d\omega. \quad (10)$$

For times immediately after t_0, ($t >\approx t_0$) the earliest part of the signal known as the Sommerfeld forerunner or precursor can be detected. The frequency of oscillation and the field amplitude for the Sommerfeld forerunner are discussed by Mojahedi et. al. [4, 34]. To summarize those results, the frequency of oscillation is given by

$$\omega_s = \sqrt{G'(0)} \Big/ \sqrt{2\left(\frac{t}{t_0} - 1\right)}, \quad (11)$$

where $G'(0)$ is the time derivative of the susceptibility kernel [33] evaluated at $t = 0$. Furthermore, for the incident wave packet proportional to t^m (m is an integer) the Sommerfeld forerunner is described by a Bessel function of order m according to

$$u(x,t) \approx a\left(\frac{t-t_0}{\gamma}\right)^{m/2} J_m\left(2\sqrt{\gamma(t-t_0)}\right); \quad (12)$$

$$\gamma = \frac{G'(0)\, t_0}{2}; \qquad \textit{for } t > t_0.$$

From the above discussion it is clear that, for a given medium if the quantity $G'(0)$ is known, the calculation of the Sommerfeld forerunner frequency of

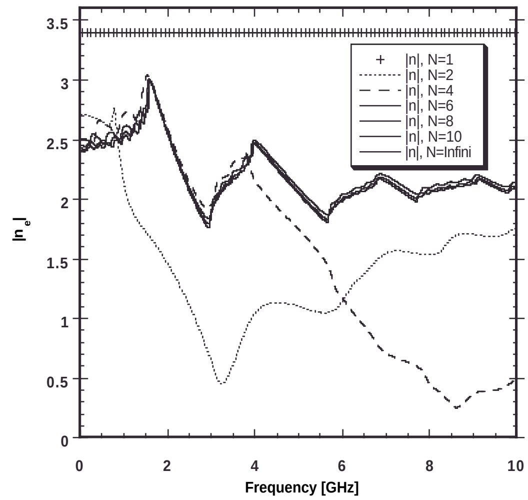

Fig. 12: Effective index for a 1DPC. The structure parameters are: $d_i = 1.76$ cm, $d_j = 1.33$ cm, $n_i = 1$, $n_j = 3.40$

oscillation and functional form is relatively straight forward. In other words, if one is capable of calculating $\varepsilon(\omega)/\varepsilon_0 - 1 = n^2 - 1$ for a 1DPC, undersized waveguide, or any other photonic barrier used in the superluminal experiments, then one can perform the inverse Fourier transform and the differentiation operation to obtain $G'(0)$. For example, let us consider the case of 1DPC used in the experiments discussed in Sections. II and III.

At the normal incidence the dispersion relation (K vs. ω) can be obtained from

$$\cos(K\,\Lambda) = \cos\left(\frac{\omega\, n_i\, d_i}{c}\right)\cos\left(\frac{\omega\, n_j\, d_j}{c}\right) - \frac{1}{2}\left(R + R^{-1}\right)\sin\left(\frac{\omega\, n_i\, d_i}{c}\right)\sin\left(\frac{\omega\, n_j\, d_j}{c}\right), \qquad (13)$$

where R is the ratio of the indices given by $R = n_i/n_j$, Λ is the one-period length $\Lambda = d_i + d_j$, and K is the Bloch wave vector. The above equation can be used to solve for the real and imaginary parts of the Bloch wave vector, and Eqs. (14)-(16), below, can in turn be used to transform the photonic crystal spatial dispersion [Eq. (13)] to a more manageable temporal dispersion

$$\mathrm{Re}(n_e) = n'_e = \frac{c}{\omega}\,\mathrm{Re}[K(\omega)], \qquad (14)$$

$$\mathrm{Im}(n_e) = n''_e = \frac{c}{\omega}\,\mathrm{Im}[K(\omega)], \qquad (15)$$

$$|n_e| = \left[(n'_e)^2 + (n''_e)^2\right]^{1/2} = \frac{c}{\omega}\,|K(\omega)|. \qquad (16)$$

The results are shown in Fig. (12) which displays our first attempt in obtaining an effective index for a 1DPC, with 1, 2, …, and infinite number of dielectric slabs. The next step is to perform the Fourier transform indicated by Eq. (10), followed by the differential operation evaluated at time equal to zero. Having obtained the quantity $G'(0)$, the frequency of oscillation and the functional form of the Sommerfeld forerunner in a 1DPC can be arrived at with the help of Eqs. (11) and (12).

VI. Superluminal Propagation and Quantum Noise in the Limit of Very Weak Pulse.

The question of superluminality in the limit of very weak pulse (one or few photons) was considered in a recent work [35]. For the sake of brevity, we refer the interested reader to Ref. (36) for a complete and detailed analysis of the situation. Here, we suffice to mention that according to Aharonov et. al. [36] in the limit of few photons, signal must be exponentially large in order to distinguish it from the quantum noise. In other words, the signal-to-noise ratio becomes vanishingly small. In Ref. (36) this assertion is investigated and it is seen that if the condition stated by Aharonov et. al. is replaced by a weaker condition, the signal-to-noise ratio can exceed unity even for one photon pulse. It is worth mentioning that the original experiment by Chiao and Steinberg, [2] although involved the detection of single photon, but the results were interpreted in terms of statistics of many photons.

VII. Concluding Remarks: A Discussion for General Public

A simple yet interesting description of superluminal propagation can be found at web link http://www.abqjournal.com/scitech/180964scitech11-19-00.htm.
This article written by John Fleck, the science writer for Albuquerque Journal, tries to explain our newly published paper in *Physical Review E* to the general public. To use John's analogy consider two dragsters competing against each other, driving the same exact cars and traveling the same exact distances. However, whereas one of the dragsters travels through air (vacuum if you like) with the maximum allowable speed, the other driver travels through a series of barriers normally thought to slow his car. The question is then the following: What does the referee at the end line observe? The answer depends on the referee detection equipment. If the referee is well equipped with the most sensitive and expensive detection systems he or she will observe that the front bumpers of the two cars arrive at the finishing line at exactly the same instance. The referee will also observe that the bulk (the main body, the cockpit and the driver) of the dragster's car who tunneled through the barriers reaches the end line

sooner than his challenger. Interestingly, if the race is decided by arrival of the cars main body or if the referee is not equipped with the most sensitive detection apparatus, he or she will invariably call the race for the tunneling dragster.

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Geometrodynamics, Inertia and the Quantum Vacuum

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ABSTRACT

Why does **F** equal ma in Newton's equation of motion? How does a gravitational field produce a force? Why are inertial mass and gravitational mass the same? It appears that all three of these seemingly axiomatic foundational questions have an answer involving an identical physical process: interaction between the electromagnetic quantum vacuum and the fundamental charged particles (quarks and electrons) constituting matter. All three of these effects and equalities can be traced back to the appearance of a specific asymmetry in the otherwise uniform and isotropic electromagnetic quantum vacuum. This asymmetry gives rise to a non-zero Poynting vector from the perspective of an accelerating object. We call the resulting energy-momentum flux the *Rindler flux*. The key insight is that the asymmetry in an accelerating reference frame in flat spacetime is identical to that in a stationary reference frame (one that is not falling) in curved spacetime. Therefore the same Rindler flux that creates inertial reaction forces also creates weight. All of this is consistent with the conceptualizaton and formalism of general relativity. What this view adds to physics is insight into a specific physical process creating identical inertial and gravitational forces from which springs the weak principle of equivalence. What this view hints at in terms of advanced propulsion technology is the possibility that by locally modifying either the electromagnetic quantum vacuum and/or its interaction with matter, inertial and gravitational forces could be modified.

INTRODUCTION

Why does **F** equal ma in Newton's equation of motion, $\mathbf{F} = m\mathbf{a}$?
How does a gravitational field produce a force?
Why are inertial mass and gravitational mass the same?

These are questions that are usually thought to be more appropriate for philosophers than for physicists, since the apparent facts of nature addressed in these questions are generally regarded as axiomatic.[1] If one assumes that one plus one equals two, plus a limited number of additional axioms, one can develop a self-consistent system of mathematics, but one has to start with such assumptions. In the realm of geometry, the discovery of non-Euclidean geometry in the 19th century taught us that other, non-intuitive assumptions are possible, and indeed, Riemannian geometry became the basis for physics in Einstein's general relativity (GR). Alternate foundational assumptions can lead to new insights.

Since 1991 we have been engaged in investigations involving the nature of inertia based on the foundational assumption that the electromagnetic quantum vacuum, also called the zero-point field or zero-point fluctuations, is a real and underlying universal sea of energy capable of interacting with matter, and that this interaction may be described using the techniques of stochastic electrodynamics (SED).[2] Following a successful multiyear NASA-funded investigation at Lockheed Martin and California State University at Long Beach, the privately-funded California Institute for Physics and Astrophysics (CIPA) was established in 1999 specifically to study the electromagnetic quantum vacuum and its effects. A group of five postdoctoral fellows with expertise in quantum electrodynamics, superstring and M-brane theory, general relativity, plasma physics and Casimir effects are engaged in theoretical efforts to come to a deeper understanding of foundational questions in physics and to examine the possible nature and degree of electromagnetic quantum vacuum–matter interactions both within and beyond the SED approximations. CIPA has also funded projects by experts at several universities directed toward the general goal of explaining the origin of inertia and certain aspects of gravitation and other relevant physical and astrophysical effects as due to the electromagnetic quantum vacuum.

It appears that all three of the seemingly axiomatic foundational questions posed above have an answer involving an identical physical process: interaction between the electromagnetic quantum vacuum and the fundamental charged particles (quarks and electrons) constituting matter. All three of these effects and equalities can be traced back to the appearance of a specific asymmetry in the otherwise uniform and isotropic electromagnetic quantum vacuum. The key insight is that the asymmetry in an accelerating reference frame in flat spacetime is identical to that in a stationary reference frame in curved spacetime.

It was shown by Unruh [3] and by Davies [4] that a uniformly-accelerating detector will experience a Planckian-like heat bath whose apparent "temperature" is a result of quantum vacuum radiation. A tiny fraction of the (enormous) electromagnetic quantum vacuum energy can emerge as real radiation under the appropriate conditions. The theoretical prediction of Unruh-Davies radiation is now generally accepted and SLAC physicist P. Chen has recently proposed an experiment to detect and measure it.[5] Rueda and Haisch (hereafter RH) [6] analyzed a related process and found that as perceived by an accelerating object, an energy and momentum flux of radiation emerges from the electromagnetic quantum vacuum and that the strength of this momentum flux is such that the radiation pressure force on the accelerating object is proportional to acceleration. Owing to its origin in an accelerating reference frame customarily called the *Rindler frame*, and to the relation of this flux to the existence of a *Rindler event horizon*, we call this flux of energy and momentum that emerges out of the electromagnetic quantum vacuum upon acceleration the *Rindler flux*.

If the Rindler flux is allowed to electromagnetically interact with matter, mainly but perhaps not exclusively at the level of quarks and electrons, a reaction force is produced that can be interpreted as the origin of Newton's $\mathbf{F} = m\mathbf{a}$. In this view, which we call the *quantum vacuum inertia hypothesis*, matter resists acceleration not because of some innate property of inertia, but rather because the quantum vacuum fields provide an acceleration-dependent drag force. In future attempts we and coworkers intend to examine the possible contributions of other components of the quantum vacuum besides the electromagnetic. (This is relevant to the issue of possible neutrino mass, which could not be due to the electromagnetic quantum vacuum, but might possibly be due to the vacuum fields of the weak interaction.)

GR declares that gravity can be interpreted as spacetime curvature. Wheeler coined the term geometrodynamics to describe this: the dynamics of objects subject to gravity is determined by the geometry of four-dimensional spacetime. What geometrodynamics actually specifies is the family of geodesics — the shortest four-dimensional distances between two points in spacetime — in the presence of a gravitating body. Freely-falling objects and light rays follow geodesics. However when an object is prevented from following a geodetic trajectory, a force is experienced: the well-known force called weight. Where does this force come from? Or put another way, how does a gravitational field exert a force on a non freely-falling, fixed, object, such as an observer standing on a scale on the Earth's surface? *This proves to be the identical physical process as described in the quantum vacuum inertia hypothesis, due to a non-zero Rindler flux.*

In the SED approximation, the electromagnetic quantum vacuum is represented as propagating electromagnetic waves.[7,8] These should follow geodesics. It can be shown that propagation along curved geodesics creates the identical electromagnetic Rindler flux with respect to a stationary fixed object as is the case for an accelerating object.[9] This is perfectly consistent with Einstein's fundamental assumption of the equivalence of gravitation and acceleration. An object fixed above a gravitating body will perceive the electromagnetic quantum vacuum to be accelerating past it, which is of course the same as the perception of the object when it is doing the accelerating through the quantum vacuum. Thus in the case of gravity, it would be the electromagnetic Rindler flux acting upon a fixed object that creates the force known as weight, thereby answering the second question. The answer to the third question then immediately follows. Since the same flux would be seen by either a fixed object in a gravitational field or an accelerating object in free space, the force that is felt would be the same, hence the parameters we traditionally call inertial and gravitational mass must be the same. This would explain the physical origin of the weak principle of equivalence.

All of this is consistent with the mathematics of GR. What this view adds to physics is insight into a specific physical process creating identical inertial and gravitational forces. What this view hints at in terms of advanced propulsion technology is the possibility that by locally modifying either the quantum vacuum fields and/or their interaction with matter, inertial and gravitational forces could be modified and possibly one day freely controlled.

THE ELECTROMAGNETIC QUANTUM VACUUM

The quantization of the electromagnetic field in terms of quantum-mechanical operators may be found in various standard textbooks, e.g. Loudon [10]: "The electromagnetic field is now quantized by the association of a quantum-mechanical harmonic oscillator with each mode $\mathbf{k}$ of the radiation field." This can be understood as follows: Application of the Heisenberg uncertainty relation to a harmonic oscillator requires that its ground state have a non-zero energy of $h\nu/2$. This reflects the fact that quantum mechanically a particle cannot simultaneously be exactly at the bottom of its potential well and have exactly zero momentum. There exists the same $h\nu/2$ zero-point energy expression for each mode of the electromagnetic field as for a mechanical oscillator. (Formally, mode decomposition yields that each mode can be mathematically made into a harmonic oscillator in the sense that the same differential equation is obeyed as for a mechanical oscillator.)

Summing up the energy over the modes for all frequencies, directions, and polarization states, one arrives at a zero-point energy density for the electromagnetic fluctuations, and this is the origin of the electromagnetic quantum vacuum. An energy of $h\nu/2$ per mode of the field characterizes the fluctuations of the quantized radiation field in quantum field theory. In the semi-classical representation of SED the quantum vacuum is represented by propagating electromagnetic plane waves, $\mathbf{E}^{zp}$ and $\mathbf{B}^{zp}$, of random phase having this average energy, $h\nu/2$, in each mode.

The volumetric density of modes between frequencies ν and $\nu + d\nu$ is given by the density of states function $N_\nu d\nu = (8\pi\nu^2/c^3)d\nu$. Each state has a minimum $h\nu/2$ of energy, and using this density of states function and this minimum energy — that we call the zero-point energy — per state one gets the spectral energy density of the electromagnetic quantum vacuum:

$$\rho(\nu)d\nu = \frac{8\pi\nu^2}{c^3}\frac{h\nu}{2}d\nu. \tag{1}$$

Writing this zero-point radiation together with ordinary blackbody radiation, the energy density is:

$$\rho(\nu,T)d\nu = \frac{8\pi\nu^2}{c^3}\left(\frac{h\nu}{e^{h\nu/kT}-1}+\frac{h\nu}{2}\right)d\nu. \tag{2}$$

The first term (outside the parentheses) represents the mode density, and the terms inside the parentheses are the average energy per mode of thermal radiation at temperature T plus the zero-point energy, $h\nu/2$, which has no temperature dependence. Take away all thermal energy by formally letting T go to zero, and one is still left with the zero-point term. The laws of quantum mechanics as applied to electromagnetic radiation force the existence of a background sea of electromagnetic zero-point energy that is traditionally called the electromagnetic quantum vacuum.

The spectral energy density of eqn. (1) was thought to be no more than a spatially uniform constant offset that cancels out when considering energy fluxes, but it was discovered in the mid-1970's that the quantum vacuum acquires special characteristics when viewed from an accelerating frame. Just as there is an event horizon for a black hole, there is an analogous event horizon for an accelerating reference frame. Similar to radiation from evaporating black holes proposed by Hawking [11], Unruh [3] and Davies [4] determined that a Planck-like radiation component will arise out of the quantum vacuum in a uniformly-accelerating coordinate system having constant proper acceleration $\mathbf{a}$ (where $|\mathbf{a}| = a$) with what amounts to an effective "temperature"

$$T_a = \frac{\hbar a}{2\pi c k}. \tag{3}$$

This "temperature" characterizing Unruh-Davies radiation does not originate in emission from particles undergoing thermal motions. [a] As discussed by Davies, Dray and Manogue [12]:

> One of the most curious properties to be discussed in recent years is the prediction that an observer who accelerates in the conventional quantum vacuum of Minkowski space will perceive a bath of radiation, while an inertial observer of course perceives nothing. In the case of linear acceleration, for which there exists an extensive literature, the response of a model particle detector mimics the effect of its being immersed in a bath of thermal radiation (the so-called Unruh effect).

This "heat bath" is a quantum phenomenon. The "temperature" is negligible for most accelerations. Only in the extremely large gravitational fields of black holes or in high-energy particle collisions can this become significant. Recently, P. Chen at the Stanford Linear Accelerator Center has proposed using an ultra high intensity laser to accelerate electrons violently enough to directly detect Unruh-Davies radiation.[5]

Unruh and Davies treated the electromagnetic quantum vacuum as a scalar field. If a true vectorial approach is considered there appear additional terms beyond the quasi-thermal Unruh-Davies component. For the case of no true external thermal radiation ($T = 0$) but including the acceleration effect (T_a), eqn. (1) becomes

$$\rho(\nu, T_a)d\nu = \frac{8\pi\nu^2}{c^3}\left[1 + \left(\frac{a}{2\pi c\nu}\right)^2\right]\left[\frac{h\nu}{2} + \frac{h\nu}{e^{h\nu/kT_a} - 1}\right] d\nu, \tag{4}$$

where the acceleration-dependent pseudo-Planckian Unruh-Davies component is placed after the $h\nu/2$ term to indicate that except for extreme accelerations (e.g. particle collisions at high energies) this term is negligibly small. While these additional acceleration-dependent terms do not show any spatial asymmetry in the expression for the spectral energy density, certain asymmetries do appear when the momentum flux of this radiation is calculated, resulting in a non-zero Rindler flux.[6] This asymmetry appears to be the process underlying inertial and gravitational forces.

ORIGIN OF THE INERTIAL REACTION FORCE

Newton's third law states that if an agent applies a force to a point on an object, at that point there arises an equal and opposite reaction force back upon the agent. In the case of a fixed object the equal and opposite reaction force can be traced to interatomic forces in the neighborhood of the point of contact which act to resist compression, and these in turn can be traced to electromagnetic interactions involving orbital electrons of adjacent atoms or molecules, etc.

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[a] There is likely to be a deep connection between the fact that the spectrum that arises in this fashion due to acceleration and the ordinary blackbody spectrum have identical form.

Now a similar experience of an equal and opposite reaction force arises when a non-fixed object is forced to accelerate. Why does acceleration create such a reaction force? We suggest that this equal and opposite reaction force also has an underlying cause which is at least partially electromagnetic, and specifically may be due to the scattering of electromagnetic quantum vacuum radiation. RH demonstrated that from the point of view of the pushing agent there exists a net flux (Poynting vector) of quantum vacuum radiation transiting the accelerating object in a direction opposite to the acceleration: the Rindler flux.[6] Interaction of this flux with the quarks and electrons constituting a material object would create a back reaction force that can be interpreted as inertia. One simply needs to assume that there is some dimensionless efficiency factor, $\eta(\omega)$, that in the case of particles corresponds to whatever the interaction process is (e.g. dipole scattering). In the case of elementary particles we suspect that $\eta(\omega)$ contains one or more resonances — and in the Appendix discuss why these resonances likely involve Compton frequencies of relevant particles forming a composite particle or object — but this is not a necessary assumption.

The RH approach relies on making transformations of the $\mathbf{E}^{zp}$ and $\mathbf{B}^{zp}$ from a stationary to a uniformly-accelerating coordinate system (see, for example, §11.10 of Jackson for the relevant transformations [13]). In a stationary or uniformly-moving frame the $\mathbf{E}^{zp}$ and $\mathbf{B}^{zp}$ constitute an isotropic radiation pattern. In a uniformly-accelerating frame the radiation pattern acquires asymmetries. There appears a non-zero Poynting vector in any accelerating frame, and therefore a non-zero Rindler flux which carries a net flux of electromagnetic momentum. The scattering of this momentum flux generates a reaction force, $\mathbf{F}_r$, proportional to the acceleration. RH found an invariant scalar with the dimension of mass quantifying the inertial resistance force of opposition per unit of acceleration resulting from this process. We interpret this scalar as the inertial mass,

$$m_i = \frac{V_0}{c^2} \int \eta(\nu)\rho_{zp}(\nu)\, d\nu, \tag{5}$$

where ρ_{zp} is the well known spectral energy density of the electromagnetic quantum vacuum of eqn. (1). In other words, the amount of electromagnetic zero point energy instantaneously transiting through an object of volume V_0 and interacting with the quarks, electrons and all charges in that object is what constitutes the inertial mass of that object in this view. It is change in the momentum of the radiation field that creates the resistance to acceleration usually attributed to the inertia of an object.

Indeed, not only does the ordinary form of Newton's second law, $\mathbf{F} = m_i\mathbf{a}$, emerge from this analysis, but one can also obtain the relativistic form of the second law: [6]

$$\mathcal{F} = \frac{d\mathcal{P}}{d\tau} = \frac{d}{d\tau}(\gamma_\tau m_i c,\ \mathbf{p}\ ). \tag{6}$$

The origin of inertia, in this picture, becomes remarkably intuitive. Any material object resists acceleration because the acceleration produces a perceived flux of radiation in the opposite direction that scatters within the object and thereby pushes against the accelerating agent. Inertia in the present model appears as a kind of acceleration-dependent electromagnetic quantum vacuum drag force acting upon electromagnetically-interacting elementary particles. The relativistic law for "mass" transformation involving the Lorentz factor γ — that is, the formula describing how the *inertia* of a body has been calculated to change according to an observer's relative motion — is automatically satisfied in this view, because the correct relativistic form of the reaction force is derived, as shown in eqn. (6).

ORIGIN OF WEIGHT AND THE WEAK EQUIVALENCE PRINCIPLE

Einstein introduced the *local Lorentz invariance* (LLI) principle in order to pass from special relativity to GR. It is possible to use this principle immediately to extend the results of the quantum vacuum inertia hypothesis to gravitation (details discussed in two forthcoming papers [9]).

The idea behind the LLI principle is embodied in the Einstein elevator thought experiment. He proposed that a freely-falling elevator in a gravitational field is equivalent to one that is not accelerating and is far from any gravitating body. Physics experiments would yield the same results in either elevator, and therefore a freely-falling coordinate frame in a gravitational field is the same as an inertial Lorentz frame. (This is rigorously only true for a "small elevator" since a gravitational field around a planet, say, must be radial, hence there are inevitably tidal forces which would not be the case for an ideal acceleration.) The device Einstein used to develop general relativity was to invoke an infinite set of such freely falling frames. In each such frame, the laws of physics are those of special relativity. The additional features of general relativity emerge by comparing the properties of measurements made in freely-falling Lorentz frames "dropped" one after the other.

This appraoch of Einstein is both elegant and powerful. The LLI principle immediately tells us that an object accelerating through the electromagnetic quantum vacuum is equivalent to an object held fixed in a gravitational field while the electromagnetic quantum vacuum is effectively accelerating (falling) past it. The prediction of GR that light rays deviate from straight-line propagation in the presence of a gravitating body — which Eddington measured in 1919 thereby validating GR — translates into acceleration (falling) of the electromagnetic quantum vacuum. An object accelerating through the electromagnetic quantum vacuum experiences a Rindler flux which causes the inertia reaction force. A fixed object past which the electromagnetic quantum vacuum is accelerating, following the laws of GR, experiences the same Rindler flux and the resulting force is what we call weight. That is why $m_g = m_i$ and is the basis of the weak equivalence principle.

CONCLUSIONS

Geometrodynamics is an elegant theoretical structure, but there is a very fundamental physics question that geometrodynamics has never satisfactorily addressed. If an object is forced to deviate from its natural geodesic motion, a reaction force arises, i.e. the weight of an object. Where does the reaction force that is weight come from? That same force would also be the enforcer of geodesic motion for freely falling objects. GR specifies the metric of spacetime from which geodesics can be calculated, but is there a physical mechanism to keep freely-falling objects from straying from their proper geodesics? Geometrodynamics does not provide a physical mechanism for this. It can only claim that deviations of an object from its proper geodesic motion results in an inertial reaction force. This is true but uninformative. The quantum vacuum inertia hypothesis provides a physical process generating inertia and weight.

Quantum physics predicts the existence of an underlying sea of zero-point energy at every point in the universe. This is different from the cosmic microwave background and is also referred to as the electromagnetic quantum vacuum since it is the lowest state of otherwise empty space. This sea of energy fills all of space and is absolutely the same everywhere as perceived from a constant velocity reference frame. But viewed from an accelerating reference frame, the radiation pattern of the energy becomes minutely distorted: a tiny directional flow is experienced by an accelerating object or observer, the Rindler flux. Importantly, the force resulting from that energy-momentum flow turns out to be proportional to the acceleration. When this energy-momentum flow — that arises automatically when any object accelerates — interacts with the fundamental particles constituting matter (quarks and electrons) a force arises in the direction opposite to the acceleration. This process can be interpreted as the origin of inertia, i.e. as the basis of Newton's second law of mechanics: $\mathbf{F} = m\mathbf{a}$ (and its relativistic extension).[6]

It has now been discovered that exactly the same distortion of the radiation pattern occurs in geometrodynamics when the metric is non-Minkowskian.[9] The curved spacetime geodesics of geometrodynamics affect the zero-point energy in the same way as light rays (because the zero-point energy is also a mode of electromagnetic radiation). The gravitational force causing weight and the reaction force causing inertia originate in an identical interaction with a distortion in the radiation of the zero-point energy field. Both are a kind of radiation pressure originating in the electromagnetic quantum vacuum. The underlying distortion of the radiation pattern is due to an event horizon-like effect and is related to Unruh-Davies radiation and Hawking radiation.

What the quantum vacuum inertia hypothesis accomplishes is to identify the physical process which is the enforcer of geometrodynamics or general relativity. The quantum vacuum inertia hypothesis appears to provide a link between light propagation along geodesics and mechanics of material objects. Moreover, since the distortion of the zero-point energy radiation pattern is the same whether due to acceleration or being held stationary in a gravitational field, this explains a centuries old puzzle: why inertial mass and gravitational mass are the same: both are due to the same non-zero Rindler flux. This gives us a deeper insight into Einstein's principle of equivalence.

APPENDIX: INERTIA AND THE DE BROGLIE WAVELENGTH

Four-momentum is defined as

$$\mathbf{P} = \left(\frac{E}{c}, \ \mathbf{p}\right) = (\gamma m_0 c, \ \mathbf{p}) = (\gamma m_0 c, \ \gamma m_0 \mathbf{v}), \tag{A1}$$

where $|\mathbf{P}| = m_0 c$ and $E = \gamma m_0 c^2$. The Einstein-de Broglie relation defines the Compton frequency $h\nu_C = m_o c^2$ for an object of rest mass m_0, and if we make the de Broglie assumption that the momentum-wave number relation for light also characterizes matter then $\mathbf{p} = \hbar \mathbf{k}_B$ where $\mathbf{k}_B = 2\pi(\lambda_{B,1}^{-1}, \lambda_{B,2}^{-1}, \lambda_{B,3}^{-1})$. We thus write

$$\frac{\mathbf{P}}{\hbar} = \left(\frac{2\pi\gamma\nu_C}{c}, \mathbf{k}_B\right) = 2\pi\left(\frac{\gamma}{\lambda_C}, \frac{1}{\lambda_{B,1}}, \frac{1}{\lambda_{B,2}}, \frac{1}{\lambda_{B,3}}\right) \tag{A2}$$

and from this obtain the relationship

$$\lambda_B = \frac{c}{\gamma v}\lambda_C \tag{A3}$$

between the Compton wavelength, λ_C, and the de Broglie wavelength, λ_B. For a stationary object λ_B is infinite, and the de Broglie wavelength decreases in inverse proportion to the momentum.

Eqn. (5) is very suggestive that quantum vacuum-elementary particle interaction involves a resonance at the Compton frequency. De Broglie proposed that an elementary particle is associated with a localized wave whose frequency is the Compton frequency. As summarized by Hunter [14]: "...what we regard as the (inertial) mass of the particle is, according to de Broglie's proposal, simply the vibrational energy (divided by c^2) of a localized oscillating field (most likely the electromagnetic field). From this standpoint inertial mass is not an elementary property of a particle, but rather a property derived from the localized oscillation of the (electromagnetic) field. De Broglie described this equivalence between mass and the energy of oscillational motion...as *'une grande loi de la Nature'* (a great law of nature)."

This perspective is consistent with the proposition that inertial mass, m_i, may be a coupling parameter between electromagnetically interacting particles and the quantum vacuum. Although De Broglie assumed that his wave at the Compton frequency originates in the particle itself (due to some intrinsic oscillation or circulation of charge perhaps) there is an alternative interpretation discussed in some detail by de la Peña and Cetto that a particle "is tuned to a wave originating in the high-frequency modes of the zero-point background field." [8] The de Broglie oscillation would thus be due to a resonant interaction with the quantum vacuum, presumably the same resonance that is responsible for creating a contribution to inertial mass as in eqn. (5). In other words, the electromagnetic quantum vacuum would be driving this ν_C oscillation.

We therefore suggest that an elementary charge driven to oscillate at the Compton frequency, ν_C, by the quantum vacuum may be the physical basis of the $\eta(\nu)$ scattering parameter in eqn. (5). For the case of the electron, this would imply that $\eta(\nu)$ is a sharply-peaked resonance at the frequency, expressed in terms of energy, $h\nu_C = 512$ keV. The inertial mass of the electron would physically be the reaction force due to resonance scattering of the electromagnetic quantum vacuum radiation, the Rindler flux, at that frequency.

This leads to a surprising corollary. It has been shown that as viewed from a laboratory frame, a standing wave at the Compton frequency in the electron frame transforms into a traveling wave having the de Broglie wavelength for a moving electron.[8,14,15,16] The wave nature of the moving electron (as measured in the Davisson-Germer experiment, for example) would be basically due to Doppler shifts associated with its Einstein-de Broglie resonance at the Compton frequency. A simplified heuristic model shows this, and a detailed treatment showing the same result may be found in de la Peña and Cetto [8]. Represent a quantum vacuum-like driving force field as two waves having the Compton frequency $\omega_C = 2\pi\nu_C$ travelling in equal and opposite directions, $\pm\hat{x}$. The amplitude of the combined oppositely-moving waves acting upon an electron will be

$$\phi = \phi_+ + \phi_- = 2\cos\omega_C t \cos k_C x. \qquad (A4)$$

But now assume an electron is moving with velocity v in the $+x$-direction. The wave responsible for driving the resonant oscillation impinging on the electron from the front will be the wave seen in the laboratory frame to have frequency $\omega_- = \gamma\omega_C(1 - v/c)$, i.e. it is the wave below the Compton frequency in the laboratory that for the electron is Doppler shifted up to the ω_C resonance. Similarly the zero-point wave responsible for driving the electron resonant oscillation impinging on the electron from the rear will have a laboratory frequency $\omega_+ = \gamma\omega_C(1 + v/c)$ which is Doppler shifted down to ω_C for the electron. The same transformations apply to the wave numbers, k_+ and k_-. The Lorentz invariance of the electromagnetic quantum vacuum spectrum ensures that regardless of the electron's (unaccelerated) motion the up- and down-shifting of the laboratory-frame spectral energy density will always yield a standing wave in the electron's frame.

It can be shown [8,15] that the superposition of these two oppositely-moving, Doppler-shifted waves is

$$\phi' = \phi'_+ + \phi'_- = 2\cos(\gamma\omega_C t - k_B x)\cos(\omega_B t - \gamma k_C x). \qquad (A5)$$

Observe that for fixed x, the rapidly oscillating "carrier" of frequency $\gamma\omega_C$ is modulated by the slowly varying envelope function in frequency ω_B. And *vice versa* observe that at a given t the "carrier" in space appears to have a relatively large wave number γk_C which is modulated by the envelope of much smaller wave number k_B. Hence both timewise at a fixed point in space and spacewise at a given time, there appears a carrier that is modulated by a much broader wave of dimension corresponding to the de Broglie time $t_B = 2\pi/\omega_B$, or equivalently, the de Broglie wavelength $\lambda_B = 2\pi/k_B$.

This result may be generalized to include quantum vacuum radiation from all other directions, as may be found in the monograph of de la Peña and Cetto [8]. They conclude by stating: "The foregoing discussion assigns a physical meaning to de Broglie's wave: it is the *modulation* of the wave formed by the Lorentz-transformed, Doppler-shifted superposition of the whole set of random stationary electromagnetic waves of frequency ω_C with which the electron interacts selectively."

Another way of looking at the spatial modulation is in terms of the wave function: the spatial modulation of eqn. (A5) is exactly the $e^{ipx/\hbar}$ wave function of a freely moving particle satisfying the Schrödinger equation. The same argument has been made by Hunter [14]. In such a view the quantum wave function of a moving free particle becomes a "beat frequency" produced by the relative motion of the observer with respect to the particle and its oscillating charge.

It thus appears that a simple model of a particle as an electromagentic quantum vacuum-driven oscillating charge with a resonance at its Compton frequency may simultaneously offer insight into the nature of inertial mass, i.e. into rest inertial mass and its relativistic extension, the Einstein-de Broglie formula and into its associated wave function involving the de Broglie wavelength of a moving particle. If the de Broglie oscillation is indeed driven by the electromagnetic quantum vacuum, then it is a form of Schrödinger's *zitterbewegung*. Moreover there is a substantial literature attempting to associate spin with *zitterbewegung* tracing back to the work of Schrödinger [17]; see for example Huang [18] and Barut and Zanghi [19].

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Interplay between gravity and quintessence: a set of new GR solutions

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Abstract

A set of new exact analytical general relativity (GR) solutions with time-dependent and spatially inhomogeneous quintessence demonstrate (1) a static non-empty space-time with a horizon-type singular surface; (2) time-dependent spatially homogeneous `spheres' which are completely different in geometry from the Friedmann isotropic models; (3) infinitely strong **anti-gravity** at a `true' singularity where the density is infinitely large. It is also found that (4) the GR solutions allow for an extreme `density-free' form of energy that can generate regular space-time geometries.

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Article Outline

1. Introduction

2. Solution **S±**

3. Solution S-1

4. Solution S-2

5. Solution S-3

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1. Introduction

The idea of quintessence (Q) as a dynamic, time-dependent and spatially inhomogeneous energy with negative pressure-to-density ratio ($p=wp$, $-1<w<0$) [1] provides new `degrees of freedom' in cosmology [1 and 2] and extends the variety of modern field models to include extreme forms of energy [1 and 3]. It may also stimulate a better understanding of the fundamental problem of interplay between gravity and the known field theories (for a review of this problem, see [4]).

The equation of state with $w=-1$ represents vacuum-type quintessence (VQ) which is phenomenologically described by the cosmological constant [5]; VQ is known to induce the dynamic effect of cosmological acceleration, if its density is positive. Recent data on the brightness of distant SN Ia [6] (as well as the evidence coming from the cosmic age, large scale structure, and cosmic microwave background anisotropy combined with the cluster dynamics) most probably indicate that the observed cosmological expansion is indeed accelerating if the universe is homogeneous. The physical reason for the cosmic acceleration may generally be attributed not only to VQ, but to any form of Q with $w<-1/3$, $\rho>0$ or $w>-1/3$, $\rho<0$, as seen from the Friedmann equations. In the original paper [1], positive energy for Q is preferred; in contrast with that, the whole range $-\infty<\rho<+\infty$ is considered below, for completeness and to examine whether any restrictions on the sign of energy could come from GR, if w=const. Note that the `inertial energy dominance condition', $\rho+p>0$, which is not met in the basic case of VQ, $w=-1$, is not satisfied also for some other forms of energy discussed below.

The special case $w=-1/3$ represents the only form of energy (with the linear equation of state) that can generate gravity with zero acceleration or deceleration effect in a homogeneous and isotropic universe, regardless the sign of the energy density. Gravity of this origin reveals itself only in the curvature of the four-dimensional space–time, it has no Newtonian analogs (unlike all other forms of Q, including VQ), and its nature is completely due to general relativity (GR) physics. Historically, Q with $w=-1/3$ was the first energy component that appeared in GR cosmology: in the Einstein static cosmological solution of 1917 the dynamic balance of anti-gravity of the cosmological constant and gravity of pressure-free matter gives rise to an effective equation of state with $w=-1/3$. This special type of Q with $w=-1/3$ may be called *Einstein quintessence* (EQ).

In the present Letter, some special properties of gravity produced by EQ, as well as by other extreme forms of Q in static and time-dependent, spatially homogeneous and inhomogeneous space–times are studied by means of a set of new exact analytical GR solutions. The metric of the solutions has 3D spherical symmetry,

$$ds^2=A(r,t)\,dt^2-B(r,t)\,d\Omega^2-C(r,t)\,dr^2; \qquad (1)$$

the components of the metric tensor $A(r,t)$,$B(r,t)$,$C(r,t)$ are functions of the radial coordinate r and time t, and $d\Omega^2=\sin^2\theta\, d\varphi^2+d\theta^2$.

Four major new results are reported in the Letter. (1) The interplay between gravity and Q is capable of creating a static non-empty space-time with a horizon-type singular surface. (2) This interplay is also revealed in the formation of time-dependent spatially homogeneous `spheres' which are completely different from the Friedmann isotropic models and have no analogs in Newtonian gravity. (3) Q can induce infinitely strong anti-gravity at a `true' singularity where the density is infinitely large. (4) GR allows for an extreme `density-free' form of energy that can generate regular space-time geometries. We use units with $G=c=1$.

2. Solution S±

All `static' (no dependence on t in the metric coefficients (1)) solutions to Einstein's equations (see, for instance, [7]) with EQ equation of state (w=-1/3) are given by

$$\begin{aligned} B(r) &= r^2, \qquad C = \frac{r^4}{a^2}\frac{(A')^2}{A}, \\ 8\pi\rho &= \frac{3a^2}{r^3}\frac{A}{(A')^2}\left(\frac{A''}{A'}+\frac{2}{r}\right), \end{aligned} \tag{2}$$

where $A(r)$ is determined from a quadratic equation

$$kA^2 + \frac{2}{a^2}A + b + \frac{1}{r^2} = 0, \tag{3}$$

with three arbitrary constants k, b and $a^2>0$. For $k \neq 0$ the two (S±) solutions thus are

$$\begin{aligned} A(r) &= \frac{1}{ka^2}\left[-1 \pm \sqrt{K(r)}\right], \\ C(r) &= \frac{-1 \mp \sqrt{K(r)}}{(br^2+1)K(r)}, \end{aligned} \tag{4}$$

$$\begin{aligned} 8\pi\rho(r) &= -\frac{3(1-ka^4 b)}{ka^4}\left[-1 \pm \sqrt{K(r)}\right], \\ K(r) &= 1 - ka^4\left(b + 1/r^2\right). \end{aligned} \tag{5}$$

To describe the parameter cases, it is convenient to introduce $q=1-ka^4b$, so that $K(r)=q-ka^4/r^2$. Evidently, $\sqrt{K(r)}$ should be positive at least for some interval of r, which leads to the following:

(A) For $q \lessgtr 0$, $k>0$ there are no (physical) solutions.

(B) For $q<0$, $k<0$ we have `interior' solutions, $r^2 \lessgtr ka^4/q$; S+ does not have an event horizon for $q<-1/2$, its horizon coincides with the boundary $r^2=2|k|a^4$ for $q=-1/2$, there is a horizon inside the space-time for $-1/2<q<0$; apparently, S- always has no horizon.

(C) For $q=0$, $\rho=0$, $k<0$ S+ is the Schwarzschild exterior solution, S- is not physical because it is also Schwarzschild but with a negative central mass.

(D) For $q>0$, $k<0$ both solutions are `global' (space-time extends to any r), S+ has a horizon.

(E) For $q>0$, $k>0$ both are `exterior' solutions, $r^2 \gtrless ka^4/q$, S+ has no horizon for $0<q<1/2$, its horizon coincides with the boundary $r^2=2ka^4$ for $q=1/2$, there is a horizon inside the space-time for $q>1/2$.

Note that whenever $r=0$ is within the space-time, solutions S± have there a true (non-coordinate) singularity: both the Ricci curvature and the density are infinite at $r=0$. For S- this is a naked singularity, with no horizon around it. Note also that in the limit $k \longrightarrow 0$ S+ goes to the solution S-1, which is obtained from Eq. (3) with $k=0$ and is discussed immediately below, while S- is singular.

3. Solution S-1

If k=0 in Eq. (3), we have a particular solution for EQ of an especially simple form:

$$A(r) = A_0\left(1 - \frac{1}{\alpha r^2}\right), \qquad B(r) = r^2,$$
$$C(r) = \frac{2}{\alpha r^2}\left(1 - \frac{1}{\alpha r^2}\right)^{-1}. \tag{6}$$

$$8\pi\rho = \frac{3}{2}\alpha\left(\frac{1}{\alpha r^2} - 1\right). \tag{7}$$

where α=-b and $A_0 = a^2\alpha/2$. To keep the proper signature of the metric as $r \rightarrow \infty$, we require $A_0>0$, so that $\alpha>0$; without loss of generality, we set A_0=1, i.e., $a^2=2/\alpha=-2/b>0$. Let us discuss this solution in more detail, setting, for simplicity, α=1.

(A) The space-time of the solution S-1 has a horizon at r=1 where the components of the metric tensor $g_{00}=A(r)$ and $g_{11}=-C(r)$ change their signs. The horizon separates (or connects) a static spatially inhomogeneous exterior space (E-space) at r>1 and a `hidden' interior object (I-object) at r<1. These two regions are similar to R- and T-regions, respectively, as described by Novikov [8] for the Schwarzschild solution. The true singularity with the infinite Ricci curvature and density is at r=0. The density in S-1 may be regarded as consisting of two components with the same equation of state: one is uniform and negative, $8\pi\rho_-=-3/2<0$, the other is non-uniform (`isothermal' law) and positive, $8\pi\rho_+(r)=3/2r^2>0$. The first one dominates the E-space, and the other one dominates the I-object; the total density changes its sign at the horizon.

(B) The `energy equation' introduced for the metric of Eq. (1) by Lemaître (see Ref. [5]) may be used to find an analog of the Newtonian gravitational potential as one of the physical characteristics of gravity produced by EQ in S-l. The equation has a form of energy conservation relation, $(1/2)(dB^{1/2}/dt)^2-m(r,t)/r=E$, where $E=C^{-1}(dB^{1/2}/dr)^2-1$ and $m(r,t)$ is the Newtonian analog of gravitating mass. In S-1, the Newtonian mass proves to be $m(r)=(3/4)r[1-(1/3)r^2]$, and the Newtonian potential $u(r)=-m/r=-(3/4)[1-(1/3)r^2]$ describes `the Newtonian component' of gravity produced by EQ in S-1. The potential u is finite at the true singularity ($u(0)=-3/4$) (unlike that in the Schwarzschild solution) and goes to $+\infty$ at spatial infinity where the density becomes constant (see below). On the singular surface, $m(1)=1/2$, and so $2|u(1)|=1$ (like that in the Schwarzschild solution).

(C) EQ gravity in S-1 is not reduced to Newtonian gravity completely; in particular, the dynamic effect of acceleration is essentially different in S-1 from what may be produced by the Newtonian potential u. The total accelerating effect can be evaluated in terms of the effective potential, $U(r)$, which may be derived using the fact that S-1 describes EQ in a state of hydrostatic equilibrium: its pressure and self-gravity are balanced in the E-space. The pressure gradient produces radial acceleration $F_p=-(dp/dr)(\rho+p)^{-1}=[8\pi(r^3-r)]^{-1}$, which is positive. So the gravity acceleration is $F=-F_p=-[8\pi(r^3-r)]^{-1}$; it is negative, and therefore gravity is attracting. The effective gravitational potential responsible for this attraction is $U=(1/2)\ln[r^2/(r^2-1)]$.

(D) S-1 can be rewritten in the E-space as

$$ds^2 = \tanh^2\left(\chi/\sqrt{2}\right)\, dt^2 - \cosh^2\left(\chi/\sqrt{2}\right)\, d\Omega^2 - d\chi^2. \tag{8}$$

$$8\pi\rho = -\frac{3}{2}\tanh\left(\chi/\sqrt{2}\right). \tag{9}$$

with the new spatial coordinate χ related to r by $r = \cosh(\chi/\sqrt{2})$; its range is from zero to infinity. The density decreases monotonically from zero at χ=0 to -3/2 at $\chi=\infty$. This form of S-1 may possibly be considered both in relation to and independently of the I-object. In the limit $r \rightarrow \infty$, where the density is spatially homogeneous, the metric of S-1 takes the form $ds^2=dt^2-r^2\,d\Omega^2-2r^{-2}\,dr^2$, or $ds^2 = dt^2 - \exp(\sqrt{2}\chi)\,d\Omega^2 - d\chi^2$. Since the general static solution for EQ in the homogeneous and isotropic 3-space has the form $ds^2=dt^2-r^2\,d\Omega^2-(1-kr^2/a^2_0)^{-1}\,dr^2$, $8\pi\rho=-24\pi\rho=3k/a^2_0$ (k=1,0,-1 is the sign of 3-curvature, a_0 is an arbitrary scalling constant), one can see that the metric of (2) and (4) reduces to the isotropic metric with k=-1 and a_0=1/2 in the limit $r\longrightarrow\infty$. For comparison: k=1, a_0=1 in the Einstein static solution.

(E) Since $A(r)$ and $C(r)$ in S-1 change their signs at the singular surface, the signature of the metric of the I-object is (- - - +). This means that the coordinate r becomes time-like, and the coordinate t becomes space-like inside the I-object. The same is true for the Schwarzschild space-time [8]. Because of that, the density of the I-object depends only on the time-like coordinate, thus it is spatially homogeneous. However, in contrast with the Schwarzschild space-time, a formal replacement of g_{00} with g_{11} and vice versa, which transforms the signature of the I-object to the `ordinary' type (+-- -), does not work for S-1, because the metric resulting from Eqs. (2) after this transformation is not a solution to the GR equations.

4. Solution S-2

GR equations for the same metric of Eq. (1) allow for the following time-dependent particular solution

$$A(t) = \tfrac{1}{4}\left(n^2 - 4\right) = \text{const} > 0, \quad B(t) = t^2, \qquad C(t) = t^n, \tag{10}$$

$$8\pi\rho = \tfrac{n(n+4)}{n^2-4}\,\tfrac{1}{t^2}, \qquad p = w\rho, \quad n = -\tfrac{4w}{1+w} = \text{const}. \tag{11}$$

The parameter range of this solution apparently consists of two parts: n>2 (-1<w<-1/3) and n<-2 (|w|>1; this is not Q as defined above). Note that both VQ (w=-1) and EQ (w=-1/3) are outside this range.

(A) The most striking feature of this solution (S-2) is that A, C and even B do not depend on r, and are functions of the time only. One may see here a similarity to the I-object of S-1 whose metric also depends on the time-like coordinate only. A closer similarity may be recognized with the `T-sphere' found by Ruban [9] for pressure-free matter and the same S-2 symmetry of 3-space with $B=B(t)$. The density and pressure are spatially homogeneous (functions of the time only) in both the S-2 and Ruban's T-sphere. Time t varies in S-2 from $-\infty$ to $+\infty$, and the density varies from zero at $t\longrightarrow\pm\infty$ to infinity in the (true) singularity t=0 which has the same character as that in homogeneous and isotropic cosmological models. However, there are no coordinate transformations that could reduce S-2 and Ruban's T-sphere to the FRW metric with the isotropic 3-space.

(B) Unlike the Friedmann solutions, gravity in S-2 and Ruban's T-sphere does not have any Newtonian analogs. Rather, the space-time of this special type has common features with anisotropic spatially homogeneous cosmological models (cf. [9]).

(C) The pressure, $p=-n^2/[8\pi(n^2-4)t^2]$, is negative in S-2, while the density may be either positive or negative. The density is positive if w is in `the Q range' -1<w<-1/3 (n>2). (Note that in the isotropic 3-space Q with w in this range produces positive acceleration, see Section 1.) The density is also positive for w>1 (i.e., -4<n<2), but it is negative when w<-1 (n<-4).

(D) The density turns to zero for $w=\infty$ (n=-4). This case describes a form of energy with ρ=0, p<0, which is perhaps the most extreme form of Q. As we see, GR does not exclude the equation of state with $w=\infty$, and gives a regular solution for it, $A(r)=3$, $B(r)=t^2$, $C=t^{-4}$. `Density-free' energy may also be in a state of hydrostatic equilibrium (see below).

5. Solution S-3

A power law particular static solution, which is a counterpart to S-2, is also allowed by the GR equations for the metric of Eq. (1):

$$A(r) = r^n, \qquad B(r) = r^2, \qquad C(r) = \tfrac{1}{4}\left(4 + 4n - n^2\right) = \mathrm{const} > 0. \tag{12}$$

$$8\pi\rho = \frac{n(4-n)}{4+4n-n^2}\frac{1}{r^2}, \qquad p = w\rho, \qquad n = \frac{4w}{1+w}. \tag{13}$$

The parameter range here looks even more peculiar: $-2(\sqrt{2}-1) < n < 2(\sqrt{2}+1)$, which corresponds to the two intervals for the values of w, $w > -(\sqrt{2}-1)/(\sqrt{2}+1) > -1/3$ and $w<-1$. Neither VQ nor EQ are within this range, and the solution relates to Q only when $-(\sqrt{2}-1)/(\sqrt{2}+1) < w < 0$.

(A) Similar to S-1 and S-2, solution S-3 depends on one coordinate only, and the true singularity of all the three solutions is at the origin of this coordinate. The positive component of density in S-1, and the total densities in S-2 and S-3 follow the inverse square law. Both S-1 and S-3 describe Q in a state of hydrostatic equilibrium.

(B) The pressure, $p=n^2/[8\pi(4+4n-n^2)r^2]$, is positive in S-3 for any $n \neq 0$. At $n=0$ the pressure and density are both identically zero. In this case, $A=1$, $C=1$, and the metric of S-3 turns to the Lorentz metric of empty space-time. The density in S-3 is positive for $0<n<4$ and negative otherwise.

(C) The density vanishes also for $n=4$, $w=\pm\infty$. This is the `density-free' ($\rho=0$, $p>0$) form of energy, and S-3 (same as S-2 above) gives a regular metric for this case: $A=1$, $B(r)=r^2$, $C(r)=r^4$. The fact that this form of energy is in the state of hydrostatic equilibrium shows that `density-free' energy has its inertial mass (per unit volume) $\rho_i=p$ which is equal to its passive gravitational mass, and that the active mass density is positive.

(D) For $n \neq 0$, the sign of the active gravitating mass depends on the sign of n. If n is positive, the mass is positive; but if n is negative (and thus w is negative), the active mass is negative also. In terms of Newtonian physics, the negative mass produces a positive acceleration, which goes to infinity as $r \to 0$, and so anti-gravity is infinitely strong at the singularity. Whether it is capable, under these conditions, of producing `auto-emission' of particles from the singularity (where the density is infinite), and/or enhance quantum evaporation of particles from the singularity, should be discussed separately.

(E) S-3 describes hydrostatic equilibrium of not only Q with negative w, but also, for instance, of ultra-relativistic fluid ($w=1/3$, $n=1$, $C=7/4$) and of Zeldovich ultra-stiff fluid ($w=1$, $n=2$, $C=2$).

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Classical analogous of quantum cosmological perfect fluid models

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Abstract

Quantization in the minisuperspace of a gravity system coupled to a perfect fluid, leads to a solvable model which implies singularity free solutions through the construction of a superposition of the wavefunctions. We show that such models are equivalent to a classical system where, besides the perfect fluid, a repulsive fluid with an equation of state $p_Q=\rho_Q$ is present. This leads to speculate on the true nature of this quantization procedure. A perturbative analysis of the classical system reveals the condition for the stability of the classical system in terms of the existence of an **anti-gravity** phase.

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Article Outline

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The existence of an initial singularity is one of the major drawbacks of the so-called standard cosmological model. It is a general belief that such problem can be solved through the employment of a quantum theory of gravity. Indeed, near the singularity sub-Planckian scales are reached and a classical description of the Universe under this situation is not appropriate. However, there is no consistent quantum theory of gravity until now, and in this sense the problem of the initial singularity remains of actuality. On the other hand, it is possible to construct a quantum model for the Universe as a whole, through the Wheeler–DeWitt equation, based in the ADM decomposition of the gravity sector, which leads to a Hamiltonian formulation of general relativity, from which a canonical quantization procedure can be applied. This gives birth to quantum cosmology [1 and 2].

Quantum cosmology is not free from problems. First, it can be applied only to geometries where a foliation is possible. Moreover, the Hamiltonian formalism leads to a breakdown of general covariance, and the notion of time is lost [3]. There are some recent proposals by which this notion of time can be recovered. One of these proposals is based in the coupling of the gravity sector to a perfect fluid. Using the Schutz's formulation of a perfect fluid [4], a quantization procedure is possible. The canonical momentum associated with the perfect fluid appears linearly in the Wheeler–DeWitt equation, permitting to rewrite this equation in the form of a Schrödinger equation and a time coordinate associated with the matter field can be identified.

Solutions based on this approach reveal that a superposition of the wavefunctions which are solutions of the resulting Schrödinger equation leads to a singularity-free Universe [5, 6, 7 and 8]. The behaviour of the scale factor may be determined in two different ways: calculating the expectation value of the scale factor, in the spirit of the many worlds' interpretation of quantum mechanics; evaluating the Bohmian trajectories in the ontological formulation of quantum mechanics. The results are essentially the same in both approaches and the scale factor display a bounce, the singularity never being reached. It must be noted that even if the two procedures are technically equivalent, they are conceptually very different from each other; there are claims that from the conceptual point of view only the ontological formalism can be consistently applied to quantum cosmology [2].

The existence of a bounce indicates that there is a repulsive effect, of quantum origin, when the scale factor approaches the singularity. In this Letter we study more in detail such scenario. It is shown that the quantum scenario can be reproduced exactly by a very simple classical model where a repulsive fluid is added to the normal perfect fluid. It is surprising that the repulsive fluid is always the same, given by a stiff matter equation of state $p_Q=\rho_Q$, independently of the content of the normal fluid. The existence of this classical analogous of the quantum model leads us to ask questions on the true nature of the quantization in this case. Under which conditions the features of a quantum system can be exactly reproduced by a classical system? Our analysis is restricted to a perfect fluid coupled to gravity system, where the notion of time is recovered. But we sketch some considerations on other situations where gravity is coupled to matter fields.

The existence of a classical analogous of the quantum model allows us to perform a perturbative analysis establishing under which conditions the repulsive phase near singularity may be stable or not. In fact, when the mechanism responsible for the avoidance of the singularity implies the violation of the strong energy condition only, we can expect this configuration to be stable; but, our analysis suggests that the quantum effects are due to a real anti-gravity phase, which can lead to instabilities under certain conditions.

In the perfect fluid formulation developed by Schutz, the degrees of freedom associated with the fluid are given by five scalar potentials in terms of which the four velocity is written:

$$u_\mu = \frac{1}{\mu}(\phi_{,\nu} + \zeta\beta_{,\nu} + \theta S_{,\nu}), \qquad (1)$$

where μ is the specific enthalpy. The four velocity is subjected to the condition

$$u_\nu u^\nu=1 \qquad (2)$$

what enables us to express the specific enthalpy in terms of the other five potentials. From now on, we work in natural units, for which $G=c=\hbar=1$. The action is then given by

$$S = \int_M d^4x\sqrt{-g}R + 2\int_{\partial M} d^3x\sqrt{h}h_{ij}K^{ij} + \int_M d^4x\sqrt{-g}p. \qquad (3)$$

where h_{ij} is the metric on the spatial section, K_{ij} is the extrinsic curvature and p is the pressure of ordinary matter. Action (3) is apparently non-covariant because of the pressure term. But, in fact, the constraints intrinsic to this formalism permit to recover the covariance.

We will consider from now on the Robertson–Walker flat geometry (the spatial section must be compact in order to be consistent with the boundary conditions)

$$ds^2=N^2\, dt^2-a(t)^2 h_{ij}\, dx^i\, dx^j. \tag{4}$$

We assume a barotropic equation of state $p=\alpha\rho$. Analyzing the conjugate momentum, and eliminating non-physical degrees of freedom, we can reduce action (3) to [6]

$$S = \int \left\{ \dot{a}p_a + \dot{\phi}p_\phi + \dot{S}p_S - NH \right\}. \tag{5}$$

where

$$H = -\frac{p_a^2}{24a} + p_\phi^{\alpha+1} a^{-3\alpha} e^S. \tag{6}$$

There are three cases which will interest us here: α=-1, α=1/3 and α=0. The dynamical vacuum (α=-1) has been studied in [6], the radiative fluid (α=1/3) in [5, 8 and 9], while the dust case (α=0) was treated in [7].

Following the Schutz formalism for the description of perfect fluid, and specializing it to a dust fluid, with p=0, we obtain the following Lagrangian:

$$L = \dot{a}p_a + \dot{\phi}p_\phi - NH. \tag{7}$$

where ϕ is the dust variable, with p_ϕ being its conjugate momentum, and H is the Hamiltonian

$$H = -\frac{p_a^2}{24a} + e^S p_\phi. \tag{8}$$

Classically, this system admits, for the flat case, the well-known dust solution $a \propto t^{2/3}$, where t is the proper time, or equivalently $a \propto \eta^2$, where η is the conformal time.

Now, we perform the canonical transformation

$$\tau=p_S e^{-S} p_\phi^{-1},\ \pi_\tau=p_\phi e^S, \tag{9}$$

reducing the Lagrangian to the form

$$H = -\frac{p_a^2}{24a} + p_\tau. \tag{10}$$

Imposing the quantization rules

$$p_a \to -i\frac{\partial}{\partial a}, \qquad p_\tau \to -i\frac{\partial}{\partial \tau}. \tag{11}$$

and considering that the Hamiltonian becomes an operator which acts on the wavefunction annihilating it,

$$\hat{H}\Psi = 0. \tag{12}$$

we obtain the following partial differential equation governing the behaviour of the wavefunction:

$$\frac{1}{24}\frac{\partial^2 \Psi}{\partial a^2} - ia\frac{\partial \Psi}{\partial \tau} = 0. \tag{13}$$

The fact that the conjugate momentum p_τ associated to the dust fluid variable appears linearly in the Hamiltonian, implies that the Wheeler–DeWitt equation in the minisuperspace assumes a form similar to the Schrödinger equation with τ playing the role of time. It is possible to show, through the canonical transformations, that in this cases it is the cosmic time. Performing the redefinitions [10]

$$a = \frac{R}{\sqrt{12}}, \qquad \tau = \frac{t}{\sqrt{12}}, \tag{14}$$

we end up with the equation

$$\frac{1}{2}\frac{\partial^2 \Psi}{\partial R^2} = iR\frac{\partial \Psi}{\partial t}. \tag{15}$$

We solve Eq. (15) using the method of separation of variables. It leads to the following decomposition of $\Psi(R,t)$:

$$\Psi(R,t)=\xi(R)e^{iEt}, \tag{16}$$

where E is a (positive) constant, and $\xi(R)$ obeys the equation

$$\xi''+2RE\xi=0. \tag{17}$$

The prime means derivative with respect to R. The solution for (17) is under the form of Bessel functions:

$$\xi(R) = \sqrt{R}\left(c_1 J_{1/3}\left(\beta R^{3/2}\right) + c_2 J_{-1/3}\left(\beta R^{3/2}\right)\right). \tag{18}$$

with $\beta = \sqrt{8E/9}$. The condition for the Hamiltonian operator to be self-adjoint leads to two possible boundary conditions:

$$\xi(0)=0 \text{ or } \xi'(0)=0. \tag{19}$$

The final results is insensitive to which boundary condition we employ. Hence, we will work with the first one, but all results are essentially recovered if the second condition is used.

The general solution is a superposition of (18). In order to have analytical expressions, we will use the following superposition:

$$\Psi(R,t) = \sqrt{R}\int_0^\infty \beta^{4/3} e^{-\gamma\beta} e^{i(9/8)\beta^2 t} J_{1/3}\left(\beta R^{3/2}\right) d\beta. \tag{20}$$

where γ is a kind of "Gaussian factor" determining the rapidity the wavefunction goes to zero as β increases. Its solution is [11]

$$\Psi(R,t) = \frac{R}{(2A)^{4/3}} e^{-R^3/4A}, \tag{21}$$

where $A=\gamma-i(9/8)t$.

It may be asked which predictions such model makes for the behaviour of the scale factor. Using the many worlds' interpretation, this mounts to evaluate the expectation value of the scale factor. It must be stressed that essentially the same result is achieved by calculating the Bohmian trajectories [2]. The measure employed in the expression is imposed again by the self-adjoint condition, and the expression for the expectation value reads

$$\sqrt{12}\langle a(t)\rangle = \langle R\rangle = \frac{\int_0^\infty R^2 \Psi(R,t)^* \Psi(R,t)\, dR}{\int_0^\infty R\Psi(R,t)^* \Psi(R,t)\, dR}. \tag{22}$$

Using (21), the expectation value for the scale factor can be calculated and the final result is

$$\langle a(t)\rangle = \frac{1}{\sqrt{12}}\left(\frac{2}{\gamma}\right)^{1/3} \frac{\Gamma(5/3)}{\Gamma(4/3)}\left(\gamma^2 + \frac{81}{64}t^2\right)^{1/3}. \tag{23}$$

The parameter t can be identified as the cosmic time due to the canonical transformations employed before. Notice that the classical behaviour is recovered for $t\longrightarrow\infty$. But, in general, the quantum model predicts a non-singular model exhibiting a bounce: when the singularity is approached, quantum effects leads to a repulsive effect, which leads to a regular transition from a contracting to an expanding phase.

A dynamical vacuum and a radiative fluid can be analyzed through the same lines as before. These problem were treated in [5, 6 and 8] and we just present the final results.

The dynamical vacuum is realized through the equation of state $p=-\rho$. Using again the Schutz formalism for this particular case, we rewrite the Hamiltonian (6), with $\alpha=-1$, as

$$H = -\frac{p_a^2}{24a} + a^3 p_T \tag{24}$$

through the canonical transformations $p_T=e^S$ and $T=-e^{-S}p_S$ [6]. Since p_T appears linearly in the Hamiltonian, it can be identified with a time variable as before, in this case in the gauge $dt=dT/a^3$, where t is the cosmic time [6]. Finding the solutions of the corresponding Wheeler–DeWitt equation, evaluating the expectation value of the scale factor, it results

$$\langle a(T)\rangle = \frac{\Gamma(4/3)}{\Gamma(7/6)}\left[\frac{64\gamma^2+9T^2}{8\gamma}\right]^{1/6}. \tag{25}$$

Asymptotically the classical solution for a cosmological constant is recovered if we choose, in the classical equations of motion, the time gauge $N=a^{-3}$ (the identification of the time coordinates can be justified rigorously [6] using the canonical transformations). In terms of the proper time, the solution (25) can be rewritten as

$$\langle a(t)\rangle = \frac{\Gamma(4/3)}{\Gamma(7/6)}\sqrt{8\gamma}\left\{\cosh\left[\frac{3}{\sqrt{8\gamma}}\left(\frac{\Gamma(4/3)}{\Gamma(7/6)}\right)^3 t\right]\right\}^{1/3}. \tag{26}$$

For the radiative case, Hamiltonian (6) reads [5 and 9], for $\alpha=1/3$ and after the canonical transformations $T=p_S e^{-S}p_\phi^{-4/3}$ and $p_T=p_\phi^{4/3}e^S$,

$$H = -\frac{p_a^2}{24a} + \frac{p_T}{a}. \tag{27}$$

Again, the conjugate momentum associated to the matter variable appears linearly and consequently we can identify this matter variable with a time variable in the gauge $dt=a\,d\eta$, with is justified through the canonical transformation as in the preceding cases. Hence this time variable is the conformal time. The wavefunctions can be determined through the Green's function method. Fixing the wavefunction at $t=0$ as [9]

$$\Psi(a) = \left(\frac{8\sigma_1}{\pi}\right)^{1/4} e^{-(\sigma_1+i\sigma_2)a^2} \tag{28}$$

and using the harmonic oscillator Green's function, integrable expression can be obtained [5 and 9]. The scale factor expectation value is given by

$$\langle a(\eta)\rangle = \frac{1}{12}\sqrt{\frac{2}{\pi\sigma_1}}\sqrt{\sigma_1^2\eta^2+(6-\sigma_2\eta)^2}. \tag{29}$$

where η is the conformal time, σ_1 and σ_2 being real parameters. Again, this solution represents a non-singular eternal Universe which coincides asymptotically with the classical radiative solution $a\propto\eta$.

It must be stressed that in all cases, the classical behaviour is recovered for large values of the proper time. Also, all solutions are singularity-free, with a bounce. Near the bounce repulsive effects appear which, in the ontological formulation, are connected with the quantum potential which corrects the classical equations of motion.

A general feature of the quantum models developed previously is the appearance of a repulsive phase for small values of the scale factor, leading to the avoidance of the singularity. In [12], it was shown that a repulsive gravity single fluid model can lead to consistent cosmological models if the curvature is negative; however, its stability is not assured in the absence of ordinary (attractive) matter. Another way of implementing a repulsive phase in classical cosmology is to consider two fluids, one that acts attractively, and the other that acts repulsively. In this case, we may have consistent solutions with flat spatial section. It is desirable that the repulsive fluid dominates for small values of the scale factor, whereas the attractive fluid dominates for large values of the scale factor. Hence, in the general, considering just the flat spatial section, we may obtain possible consistent models from

$$\left(\frac{\dot{a}}{a}\right)^2 = 8\pi G(\rho_M - \rho_Q) = \frac{C_1}{a^m} - \frac{C_2}{a^n}. \tag{30}$$

where $p_M=\alpha_M\rho_M$, $p_Q=\alpha_Q\rho_Q$, $m=3(1+\alpha_M)$ and $n=3(1+\alpha_Q)$. The subscripts M and Q stand for "normal" matter component and for "quantum" repulsive component.

Ordinarily, normal matter may be a cosmological constant, dust or a radiative fluid, corresponding to α_M=-1,0,1/3, respectively. Since it is desirable that the repulsive component dominates at small values of a, then $\alpha_Q>1/3$. We choose then a repulsive stiff matter fluid $\alpha_Q=1$, what leads to $n=6$. Hence, we will solve Eq. (30) with $n=6$ and $m=0$, 3 and 4. The solutions are the following:

$\alpha_M=-1$, $\alpha_Q=1$:

$$a(t) = \left(\frac{C_2}{C_1}\right)^{1/6} \cosh^{1/3} 3\sqrt{C_1}t. \tag{31}$$

$\alpha_M=0$, $\alpha_Q=1$:

$$a(t) = \left(\frac{C_2}{C_1}\right)^{1/3} \left[\frac{9}{4}\frac{C_1^2}{C_2}t^2 + 1\right]^{1/3}. \tag{32}$$

$\alpha_M=1/3$, $\alpha_Q=1$:

$$a(\eta) = \sqrt{\frac{C_2}{C_1}} \left[\frac{C_1^2}{C_2}(\eta - \eta_0)^2 + 1\right]^{1/2}. \tag{33}$$

The comparison of the above solutions with those obtained through the construction of a superposition of the wavefunctions resulting from the Wheeler–DeWitt equation in the minisuperspace with only the ordinary perfect fluid, reveals that they are the same provided that C_1 and C_2 are suitable functions of the parameters of the wavepackets. For the dust case, for example, we can fix

$$\begin{aligned} C_1 &= \frac{1}{12^{3/2}}\frac{9}{8}\frac{1}{y}\left(\frac{\Gamma(5/3)}{\Gamma(4/3)}\right)^3, \\ C_2 &= \frac{1}{12^3}\frac{9}{4}\left(\frac{\Gamma(5/3)}{\Gamma(4/3)}\right)^6. \end{aligned} \tag{34}$$

For the other cases, the expressions for these constants are quite similar. But notice that, in the radiative case, we have introduced a phase η_0, which can be zero only if σ_2 is also zero. Hence, wavepackets constructed from a quantum model where, besides the scale factor, there is a perfect fluid matter degree of freedom (which leads to a time coordinate) are equivalent to a classical model where gravity is coupled to the same perfect fluid plus a repulsive fluid with a stiff matter equation of state $p_Q=\rho_Q$. It is really surprising that the repulsive fluid, in the classical model, is the same irrespective of the normal fluid employed in the quantum model.

The question of reproducing the classical equations of motion from the quantum ones appears already in the ordinary quantum mechanics, and they are expressed in the so-called Ehrenfest's theorem. According to this theorem, the center of the wavepacket may follow a classical trajectory under certain conditions. Explicitly, taking the expectation values of the

Heisenberg's equations for the position and momentum operators for a particle of mass m in a potential $V(\vec{r})$, we find [13]

$$\langle \dot{\vec{r}} \rangle = \frac{\vec{p}}{m}, \tag{35}$$

$$\langle \dot{\vec{p}} \rangle = -\langle \nabla V(\vec{r}) \rangle. \tag{36}$$

These relations coincide with the classical one only if $\langle \nabla V(\vec{r}) \rangle = \nabla V(\langle \vec{r} \rangle)$. This happens only for very special forms of the potential, the harmonic oscillator being an example. Only in these special cases, we may say that the center of the wavepacket follows a classical trajectory.

However, the situation discussed here is somehow different from that analyzed in the Ehrenfest's theorem. In fact the expectation value of the scale factor of a quantum model derived from gravity and a perfect fluid of attractive nature is reproduced by a classical model where another fluid, of repulsive nature, appears. This seems somehow mysterious.

Some insights into what is happening in this case may come from the employment of the ontological interpretation of quantum mechanics. In this case, the problem of time is solved in any situation (not only when a matter field is present). In fact, the ontological interpretation predicts that the system follows a real trajectory given by the equations

$$p_q = S_{,q}, \tag{37}$$

where the subscript q designates one of the degrees of freedom of the system, and S is the phase of the wavefunction, which is written as $\Psi = Re^{iS}$, R and S being real functions. The equation of motion (37) is governed not only by a classical potential V but also by a quantum potential $V_Q = \nabla^2 R/R$.

These considerations suggest that the quantum potential has, at least in the case of the quantization of perfect fluid systems, a very clear behaviour which can be classically reproduced by a repulsive stiff matter fluid. However, we must stress that even in this case we must find first the wavefunction, through the Wheeler–DeWitt equation, determining than its phase, from which the Bohmian trajectories is computed. In the quantum models studied previously, it is not possible, in principle, to identify a classical and quantum potential in terms of the scale factor from the beginning. Moreover, even if this would be possible, the classical analogous we have determined are completely independent of the Wheeler–DeWitt equation.

We may obtain more informations on the meaning of this classical analogous of a quantum system by studying the dispersion of the wavepacket. We will treat again the dust case where the wavepacket is given by (21). The calculation is standard and we obtain the following expression for the dispersion of the wavepacket:

$$\Delta a(t) = \left[\left\langle a^2(t) \right\rangle - \left\langle a(t)^2 \right\rangle \right]^{1/2} = \frac{1}{\sqrt{12}} \left(\frac{2}{\gamma} \right)^{1/3} \left[\frac{\Gamma(2)}{\Gamma(4/3)} - \frac{\Gamma(5/3)^2}{\Gamma(4/3)^2} \right]^{1/2} \left(\gamma^2 + \frac{81}{64} t^2 \right)^{1/3}. \tag{38}$$

Hence, the wavepacket disperse as time evolves; its minimal dispersion is reached in the origin $t=0$, exactly where the classical and quantum behaviours (both with just the dust fluid) do not coincide. Notice that the ratio of $\Delta a(t)$ to $\langle a(t) \rangle$ is constant, and as the wavepacket becomes more localized, the scale factor approaches the singularity. A localized wavepacket means a small value for γ. Notice that as γ becomes small, the coefficient C_2 becomes negligible compared with C_1 (Eqs. (34)), and the two-fluid model tends to approach the one fluid model.

The situation described above is very similar to what happens with a free particle in ordinary quantum mechanics: the wavepacket has its minimum width at origin and disperse as time evolves. In this case the question of the classical limit is somehow subtle. If an ensemble of classical particles, with some initial dispersion in their velocities, is settled in the origin, their trajectories do not reproduce the possible results of measurement of the free quantum particle initially; as time evolves, the dispersion of the wavepacket tends to coincide with the dispersion of the trajectories of the classical particles. This does not mean that notion of classical trajectory is recovered [13 and 14].

In quantum cosmology, however, the scenario is more complex. In this case, we may use the many worlds' interpretation [15] or the ontological interpretation [16] of quantum mechanics. In any case, the notion of trajectory is recovered. In this sense, the above results indicate that, for large values of time, the quantum trajectory coincides with the corresponding classical trajectory with suitable initial conditions, while near the origin these trajectories do not coincide. But, our analogous model, with two fluids, reproduce the quantum trajectory even in the vicinity of the origin, keeping the asymptotical agreement untouched.

Since we have a classical analogous of the bounce models determined through the Wheeler–DeWitt equation, we can investigate if the repulsive effect leading to the avoidance of the singularity may spoil the stability of the model. First of all we define what we understand here by instability. A cosmological model is considered unstable if the perturbative variables diverge when all background quantities are finite. Here, we will consider a weaker condition: the model is unstable if the perturbed quantities takes very large values in comparison with the background quantities, even if they are not divergent. This is due to the fact that, if this happens, the hypothesis of homogeneity and isotropy, employed in the definition of the background, are compromised.

Let us consider our non-singular classical system. It can be written as

$$R_{\mu\nu} = 8\pi G\left[\overset{M}{T}_{\mu\nu} - \frac{1}{2}g_{\mu\nu}\overset{M}{T}\right] - 8\pi G\left[\overset{Q}{T}_{\mu\nu} - \frac{1}{2}g_{\mu\nu}\overset{Q}{T}\right], \tag{39}$$

$$\overset{M}{T}{}^{\mu\nu}{}_{;\mu} = 0, \tag{40}$$

$$\overset{Q}{T}{}^{\mu\nu}{}_{;\mu} = 0. \tag{41}$$

We perturb these equations in the usual way, introducing the quantities

$$g_{\mu\nu} = \overset{0}{g}_{\mu\nu} + h_{\mu\nu}, \qquad \rho_M = \overset{0}{\rho}_M + \delta\rho_M,$$
$$\rho_Q = \overset{0}{\rho}_Q + \delta\rho_Q.$$

The computation of the perturbed equations is quite standard [17], and we just present the final equations, at linear level:

$$\ddot{h} + 2\frac{\dot{a}}{a}\dot{h} = \frac{1}{\alpha_M - \alpha_Q}\left[-(1+3\alpha_M)\left(2\frac{\ddot{a}}{a} + (1+3\alpha_Q)\frac{\dot{a}^2}{a^2}\right)\Delta_M + (1+3\alpha_Q)\left(2\frac{\ddot{a}}{a} + (1+3\alpha_M)\frac{\dot{a}^2}{a^2}\right)\Delta_Q\right], \tag{42}$$

$$\dot{\Delta}_M + (1+\alpha_M)\left(\Psi - \frac{\dot{h}}{2}\right) = 0, \tag{43}$$

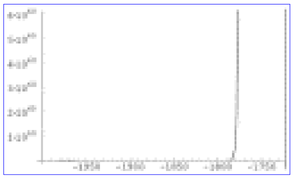
$$(1+\alpha_M)\left[\dot{\Psi} + (2-3\alpha_M)\frac{\dot{a}}{a}\Psi\right] - \frac{n^2}{a^2}\alpha_M\Delta_M = 0, \tag{44}$$

$$\dot{\Delta}_Q + (1+\alpha_Q)\left(\theta - \frac{\dot{h}}{2}\right) = 0, \tag{45}$$

$$(1+\alpha_Q)\left[\dot{\theta} + (2-3\alpha_Q)\frac{\dot{a}}{a}\theta\right] - \frac{n^2}{a^2}\alpha_Q\Delta_Q = 0. \tag{46}$$

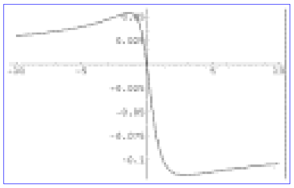
In these expressions, we have used the following definitions: $h=h_{kk}/a^2$, $\Delta_M=\delta\rho_M/\rho_M$, $\Delta_Q=\delta\rho_Q/\delta\rho$, $\Psi=\delta u_M{}^i$, $\theta=\delta u_Q{}^i$, where $\delta u_M{}^i$ and $\delta u_Q{}^i$ are the perturbations on the four velocity of the normal and repulsive fluid, respectively.

The perturbed equations presented above do not seem to admit analytical solutions for the background solutions ((31), (32) and (33)). Hence, we are obliged to perform a numerical integration. In Fig. 1, Fig. 2 and Fig. 3 we display the evolution of density perturbations for the exotic fluid for the cosmological constant, dust and radiative cases, respectively, in the long wavelength limit $n\longrightarrow 0$. The other perturbed quantities exhibits essentially the same features.



(2K)

Fig. 1. Behaviour of $\mathbf{\Delta}_Q(t)$ for n=0 with cosmological constant.



(2K)

Fig. 2. Behaviour of $\mathbf{\Delta}_Q(t)$ for n=0 with a dust fluid.

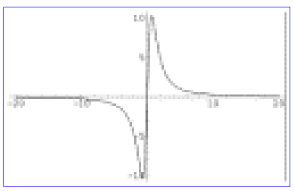


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Fig. 3. Behaviour of $\mathbf{\Delta}_Q(t)$ for n=0 with a radiative fluid.

From the numerical study performed we can expose the following conclusions. When the cosmological constant is coupled to the repulsive fluid, the bounce model is unstable. Approaching the minimum of the scale factor (which in all three cases occurs in the origin), the perturbations diverge. However, when the dust or radiative fluid is coupled to the repulsive fluid, the perturbations behave regularly during all the evolution of the Universe. Hence, these models are stable. The different behaviours for the cosmological constant and the other cases may be easily understood. Indeed, in [12] a stability study was performed for the same repulsive fluid (represented there by a free scalar field); the curvature was taken to be negative. Instabilities were found in the absence of ordinary matter. In the present cosmological constant case, as it happens also in [12], the perturbation of ordinary matter decouples completely and the metric perturbation is coupled only to the perturbation of the repulsive fluid. In contrast, for the radiative and dust cases all perturbed variables are coupled. More important, in the present cosmological constant case, and in the model studied in [12], the energy conditions are violated during all the evolution of the Universe, while for the dust and radiative cases studied here, this violation occurs only near the bounce. The violation of the energy conditions leads to a repulsive gravity effect which contributes to a very fast growing of perturbations. If it occurs for all times, this lead to divergence.

In spite of the fact that we display the results for n=0 only, for other values of n the features are very similar. For very large values of n, the perturbations exhibit strong oscillations, and they become divergent near the minimum of the scale factor for the cosmological constant case. Of course, we have studied the stability of the classical analogous of the quantum model. But, this study leads to some insights to what happens in the original framework. Indeed, the considerations made above about the expectation value of the scale factor and the dispersion of the wavepacket permits to take seriously the classical perturbative study as indication of the behaviour of the quantum model, mainly if we take the point of view that in quantum cosmology the notion of trajectory is essential. The only important drawback concerns the fact that a complete quantum perturbation should take into account excitations of degrees of freedom that were frozen in the minisuperspace approach. Other important point is what we mean by "near the bounce", where instabilities may appear. In fact, we consider it as the region where the quantum effects are dominant and all energy conditions are violated.

The main point of the present work is that the quantum model, derived from the Wheeler–DeWitt equation for gravity plus perfect fluid through the Schutz's formalism, has a classical analogous. In this classical analogous system, the perfect fluid is coupled to another perfect fluid, with a fixed equation of state $p_Q=\rho_Q$ which appears with a "wrong" sign for the gravitational coupling. The existence of this classical analogous for all equations of state of the normal fluid studied in this work, rises doubts about the true quantum nature of the original quantum cosmological scenario. It is not clear to us how to solve these doubts for the moment. But, the existence of a classical system reproducing different quantum models may indicate that the quantization of a gravity system in the minisuperspace may be not a real quantization and a more careful analysis of this problem is deserved.

In the analysis performed previously, it has been considered a specific superposition of the solutions of the Wheeler–DeWitt equation. Since these solutions are not square integrable, a superposition of them is in fact a necessity in those models. It can be argued that other types of superpositions are possible which may not be in agreement with the classical analogous treated here; all the richness of the original quantum model would not be reproduced by the classical model. However, the superposition procedure must agree with physical requirements as, for example, the localization of the wavepacket, what is the case of the preceding examples. We may guess that other possible superpositions, satisfying the same physical requirements, will lead to essentially the same results. These comments can also be applied to the question of the boundary conditions. Perhaps, the choice of other boundary conditions could lead to different scenarios. But, the boundary conditions used here are motivated by physical requirements, like the regularity of the wavefunction and the self-adjointness of the Hamiltonian operator. We may guess that any physically reasonable boundary condition would lead to similar scenarios to those presented here.

A perturbative study was performed in the classical model. It can happens that a bounce model, where the avoidance of the singularity is obtained through an anti-gravity phase, may not be a stable model. We have verified that when the normal fluid decouples from the other perturbed equations, in such a way that the metric perturbation are coupled to the repulsive fluid only, the background model is unstable. Otherwise, we can obtain stable singularity-free models with an anti-gravity phase.

We must stress that the classical analogous model reveals that the "quantum effects" exhibit an anti-gravity behaviour. That is, the singularity is avoided with conditions much more stronger than the simple violation of the strong energy condition, as it happens in many others singularity-free models [18]. It must also be emphasized that all considerations have been done for a perfect fluid quantum model. It should be important to verify if the correspondence found here remains when gravity are coupled to matter fields. In [19] the case of a free scalar field was analyzed. However, a free scalar field is equivalent to stiff matter. Consequently, the classical analogous (if still valid for this case) would contain two kinds of stiff matter, an attractive one and a repulsive one. Perhaps, the strange behaviour found in [19], with the quantum phase being recovered for large values of the scale factor, is due to this fact. This specific case deserves to be analyzed carefully.

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Gravity and antigravity in a brane world with metastable gravitons

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Abstract

In the framework of a five-dimensional three-brane model with quasi-localized gravitons we evaluate metric perturbations induced on the positive tension brane by matter residing thereon. We find that at intermediate distances, the effective four-dimensional theory coincides, up to small corrections, with General Relativity. This is in accord with Csaki, Erlich and Hollowood and in contrast to Dvali, Gabadadze and Porrati. We show, however, that at ultra-large distances this effective four-dimensional theory becomes dramatically different: conventional tensor gravity changes into scalar **anti-gravity.**

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Weak gravitation shielding properties of composite bulk $YBa_2Cu_3O_{7-x}$ superconductor below 70 K under e.m. field.

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Abstract

A high-temperature $YBa_2Cu_3O_{7-x}$ bulk ceramic superconductor with composite structure has revealed weak shielding properties against gravitational force while in a levitating state at temperatures below 70 K. A toroidal disk with an outer diameter of 275 mm and a thickness of 10 mm was prepared using conventional ceramic technology in combination with melt-texture growth. Two solenoids were placed around the disk in order to initiate the current inside it and to rotate the disk about its central axis. Samples placed over the rotating disk initially demonstrated a weight loss of 0.3-0.5%. When the rotation speed was slowly reduced by changing the current in the solenoids, the shielding effect became considerably higher and reached 1.9-2.1% at maximum.

74.72.-h High-T_c cuprates.

1 Introduction.

The behavior of high-T_c ceramic superconductors under high-frequency magnetic fields is of great interest for practical applications. Crystal structure seems to be the key factor determining all physical properties of bulk superconductors, and the interaction of this structure with external and internal e.m. fields might result in quite unusual effects. Despite a large number of studies [1, 2, 3] the nature of these interactions still remains unresolved.

Our recent experimental work [4] clearly indicated that under certain conditions single-phase bulk, dense $YBa_2Cu_3O_{7-x}$ revealed a moderate shielding effect against gravitational force. In order to obtain more information about this unusual phenomenon, a new installation was built, enabling operation with larger disks (275 mm in diameter), in magnetic fields up to 2 T and frequencies up to 10^8 Hz at temperatures from 40 to 70 K. A new experimental technique was employed to modify the structure of the ceramic superconductor. All these efforts yielded a larger value of the shielding effect (up to 0.5% in stationary conditions and to 2.1% for shorter periods), providing good hopes for technological applications.

A gravitational shielding effect of this strength has never been previously observed, and its implications present serious theoretical difficulties (see [11] for references and an analysis of some hypotheses). Thus, great attention was devoted to the elimination of any possible source of systematic errors or of spurious non-gravitational effects. The small disturbances due to air flows pointed out by some authors [9, 10] were eliminated by weighing the samples in a closed glass tube (see Section 4). The entire cryostat and the solenoids were enclosed in a stainless steel box. But probably the best evidence for the true gravitational nature of the effect is that the observed weight reductions (in %) were independent of the mass or chemical composition of the tested samples (Section 6).

This work is organized as follows. Sections 2 and 3 describe our experimental setup. Section 2 summarizes the main steps in the sinterization of the composite ceramic disk and contains information about the final properties of the disk (T_c for the two layers, J_c for the upper layer, etc.) and about the microscopic structure of the material. Section 3 describes how we obtain and control the levitation and rotation of the disk, up to an angular speed of about 5000 rpm. In Section 4 we describe the weight measurement procedure and analyze in detail possible error sources and parasitic effects. Several checks were performed to exclude any influence of spurious factors (Section 5). In Section 6 we give the maximum % shielding values obtained in dependence on the rotation speed of the disk and on the frequency of the applied magnetic field. Finally, Sections 7 and 8 contain a short discussion and our conclusions.

According to public information, a NASA group in Huntsville, Alabama, is now attempting to replicate our experiment. This is a difficult task, especially in view of the sophisticated technology involved in the construction of the large ceramic disk and in the control of its rotation. We are also aware, through unofficial channels, that other groups are working on similar experiments with smaller disks.

2 Construction of the disk.

The shielding superconducting element was made of dense, bulk, almost single-phase $YBCO$ and had the shape of a toroidal disk with an outer diameter of 275 mm, an inner diameter of 80 mm, and a thickness of 10 mm. The preparation of the 123-compound and fabrication of the disk involved mixing the initial oxides, then calcining the powder at 930^0 C in air, grinding, pressing the disk at 120 MPa, and sintering it in oxygen at 930^0 C for 12 hours with slow cooling to room temperature. After that, the disk was put back in the furnace at 600^0 C, and the upper surface was quickly heated to 1200^0 C using a planar high-frequency inductor as shown in Figure 1. During this last heating, the gap between the disk and the inductor was chosen precisely so that heating would occur only in the top 2 mm-thick layer of the disk, although the material's high heat conductivity caused some heating below this region. Finally, the disk was slowly cooled down to room temperature in a flow of oxygen and treated mechanically in order to obtain good balance during rotation. A thin (1 mm) foil of magnetic material was attached (without electric contact) to the upper surface of the disk, using hot-melt adhesive, to facilitate rotating the disk as described below, especially at the initial stages of rotation.

The phase and crystal structure of the superconductor were studied using X-ray diffraction analysis (XRD) and a scanning electron microscope (SEM) equipped with an energy dispersive spectral (EDS) analyzer. The samples were cut layer by layer from the bulk ceramic disk.

The analysis of the cross-section of the ceramic $YBa_2Cu_3O_{7-x}$ disk revealed the existence of two zones with different crystal structures. The upper part of the disk (6-7 mm thick) had an orthorhombic structure typical of the quench and melt growth process [5, 6] and consisted mainly of single-phase orthorhombic 123-compound. This material was dense, with uniformly fine grain boundaries, i.e. no impurities or secondary phases were found between the grains. Inter-grain boundaries were barely visible, indicating that there were good electrical contacts between the particles of the superconducting body and that the sintering of the material had produced a nearly perfect polycrystal lattice with no apparent defects.

The grains were less than 2 μm wide and were oriented (about 75%) with c-axis parallel to the surface of the disk. The transition temperature T_c for this region of the disk was found by direct measurements to be 94 K, with a width of 1.5-2 K. T_c was determined from the resistive transition in a variable temperature cryostat, under zero magnetic field, using an AC current and sputtered golden contacts.

The lower part of the disk, which was in contact with a water-cooled base during the high-frequency heat treatment, had a markedly different structure: randomly oriented grains, with typical grain sizes between 5 and 15 μm. The porosity of this zone varied from 5 to 9% and the material contained about 40% of the tetragonal phase. The transition temperature T_c was equal to 60 K, with a width of ca. 10 K. EDS analysis showed the presence of small inclusions of Y_2BaCuO_5 in the lower layer.

Crystal lattice parameters for these two layers, as calculated from XRD, are listed below. These are dimensions in nm:

Upper layer: a=0.381; b=0.387; c=1.165;

Lower layer: a=0.384; b=0.388; c=1.170 (orthorhombic phase);

a=0.387; c=1.183 (tetragonal phase).

The critical current density was measured for samples cut from the top of the superconducting disk. Measurements of J_c were carried out at 75 K using an AC current, four-probe method, and direct transport measurements. The accuracy for J_c determination was defined as 1 $\mu V/cm$ in a zero magnetic field, with the sample immersed in liquid nitrogen. It turned out that J_c exceeded 15000 A/cm^2. The value of J_C for the lower part of the disk was not measured, since it is not superconducting at the temperature of operation.

We also estimated the current density in the upper part of the disk while subjected to the magnetic fields usually applied during the measurements. To measure this we made a thin radial cut through the sample disk and attached electric contacts to an ampermeter, with a tecnique allowing fast on/off switching. We calibrated the currents in the driving coils that correspond to the currents inside the disk. These currents are slightly different for each new disk as the thickness of the SC part is not the same in every new sintered ceramic toroid, but we estimate their density to range between 5000 and 7000 A/cm^2.

3 Operation of the apparatus.

Two identical solenoids were placed around the superconductor using fibreglass supports, as shown in Figures 2, 4, 5. The gaps between these solenoids and the disk were large enough for it to move about 20 mm in any lateral direction. The toroidal disk was placed inside a cryostat equipped with a set of three coils (Fig. 3) that could keep it levitating when it reached the superconducting state. The angle β was between 5 and 15 degrees. This helped to keep the rotating disk in a stable position, otherwise it tended to slip aside.

A schematic of the electrical connections is shown in Fig. 6. High-frequency electric current (10^5 Hz) was first sent to the two main solenoids around the disk to initiate an internal current in the ceramics while the disk was still at room temperature. Then the system was slowly cooled down to 100 K by liquid nitrogen, and then quickly cooled by liquid helium vapors. We estimate the temperature of the disk to be lower than 70 K in stationary conditions. Thus the upper layer of the disk is superconducting in these conditions, while the lower layer is not. The main solenoids were switched off. After this, the high-frequency current was sent to the coils below the disk, and the superconductor raised up (at least 15 mm; see Section 6).

Then a small current (10^5 Hz) was sent to the main solenoids, causing the disk to begin rotating counter-clockwise with increasing speed. The rotation speed was increased up to 5000 rpm. At this point the current in the rotating coils was of the order of 8-10 A. (The diameter of the wire of these coils is 1.2 mm). This current was supplied by powerful high-frequency generators usually employed for induction heating and quenching of metals.

Most weight measurements for various objects were taken in these conditions, which can be maintained in a stable way for quite long periods (10 minutes or more). Next, the disk's rotational speed was slowly reduced by changing the current in the main solenoids (Fig. 9). The speed of rotation was regulated by means of laser beam reflections off a small piece of plastic light-reflecting foil attached to the disk.

The frequency of the e.m. field was varied from 10^3 to 10^8 Hz. Samples made of various materials were tested, including metals, glass, plastic, wood and so on. All the samples were hung over the cryostat on a cotton thread connected to a sensitive balance. The distance between the samples and the cryostat varied from 25 to 3000 mm.

4 Weight measurements. Error sources.

To measure the weight loss of the samples, we used a Dupont balance that is a part of the standard equipment for DTA and TGA (differential thermal analysis, thermo-gravimetric analysis). One of the two arms of the balance, holding the sample to be weighed, was lying within the vertical projection of the HTC disk (we call this region the "shielding cylinder"), while the other arm was well outside. The arms of the balance were up to 220 cm long. The sensitivity of the balance for masses of 10-50 g, like those employed in the measurements, is on the order of 10^{-6} g, which was sufficient to detect the observed weight loss. Three different balances were used for verification and are described below (see "Checks", Section 5).

The main error sources in the weight measurements were the following.

1. *Buoyancy and air flow.* The presence of the cryostat perturbs the air and causes weak local flows. Moreover, a much larger ascending flux is caused by the weight loss of the air in all the shielding cylinder; this also produces a pressure drop in the shielding cylinder (see Section 6). The error introduced by this effect in the weight measurements has been substantially reduced by enclosing the samples to be weighed in a long glass tube, closed at the bottom. The samples had the form of elongated objects (like big pencils). In order to set an upper limit on the buoyancy effect, some flat samples were weighed too, without enclosing them in the glass tube, in vertical and horizontal positions, and the results for the two cases were compared. It turned out that the weight loss in horizontal position was larger (by approx. 10% of the total loss) than in vertical position.

2. *Hydrostatic force.* This introduces a slight dependence of the weight loss on the density of the sample. For a material with density 1 Kg/dm^3, the Archimede pull amounts to about the 0.1% of the weight. Since the air density is slightly lower in the shielding cylinder (see above and Section 6), the Archimede pull is lower itself, but this effect can be disregarded, being of the order of 0.001% of the total weight or less.

3. *Diamagnetism.* It is known that molecular diamagnetism produces a small levitating force on samples placed in a magnetic field gradient. For a large class of materials, this force is essentially independent on the chemical composition of the material and is proportional to its weight. For instance, a standard value for the diamagnetic levitating force is the

following: in a field gradient of 0.17 T/cm the force exerted on a 1 g sample of $NaCl$, SiO_2, S or diamond is ca. equal to 16 *dyne* (about 0.016 g, or 1.6% of the weight).

Since the force is proportional to the square of the field gradient, one easily finds that the value of the field gradient corresponding to a percentage weight loss of 0.1% is about 0.04 T/cm (for comparison, we recall that the maximum weight loss we observed in stationary conditions was 0.5%). A mapping of the static field produced by our apparatus yelded in all cases smaller values of the field gradient near the disk, and much smaller values at a height of 50 cm or more above the disk, where the observed weight loss stays the same (compare Section 6). We thus conclude that the effect of molecular diamagnetism can be completely disregarded.

4. *RF fields.* The possibility of a slight levitating effect from an RF magnetic field cannot be excluded completely. However, such disturbance was attenuated, if not eliminated, by placing thick metal screens between the cryostat and the samples. Copper, aluminum, and steel screens were tested separately and in many different combinations. The individual screens had a diameter of 300 mm and a thickness of 50 mm. The presence of the screens never altered the effect.

5 Checks.

We did several checks in order to correlate more clearly the appearence of the effect to specific experimental conditions.

1. *Substituting a metal disk or a disk made totally from superconducting ceramic.* In all these cases, the shielding effect was not observed. This confirms, in our opinion, that the origin of the effect resides in the interaction between the upper (superconducting) part of the disk and the lower part, where considerable resistive phenomena take place.

2. *Measurements in vacuum, or in different gases, or in a fluid.* These measurements show that the effect exists in these conditions, too, and has the same magnitude as in air. For these cases, however, we cannot furnish data as precise as the measurements taken in air yet, because the experimental conditions are more difficult and the necessary statistics

are still being accumulated. Measurements in vacuum or in gases other than air (N_2, Ar) are hampered by the fact that the samples and the analytical balance must be enclosed in a sealed container. For the measurements in fluids (H_2O, C_2H_5OH) Archimede pull is more relevant and thus complicates measurements.

3. *An AC field is indispensable.* The shielding effect was completely absent when only static magnetic fields were employed.

4. *Other weighing techniques.* Although the most accurate measurements have been taken with the Dupont balance for precision differential thermogravimetric analysis, we employed for verification three other balances. In the latest runs, using heavier samples with weights varying from 100 g to 250 g, a standard analytical balance was used. Given these masses and the balance's accuracy (0.01 g), weight losses of 0.01% were easy to detect. In addition, we used two other types of balances, sketched in Fig. 8. The first one is a torsion balance, whose oscillation period depends on the tension of the wire and thus on the weight of a suspended sample. This period can be measured with high accuracy through a laser beam reflected by a mirror attached to the wire. Finally, we employed a spring balance whose movements are detected by an induction transducer.

6 Results.

The levitating disk revealed a clearly measurable shielding effect against the gravitational force even without rotation. In this situation, the weight-loss values for various samples ranged from 0.05 to 0.07%. As soon as the main solenoids were switched on and the disk began to rotate in the vapors of liquid helium, the shielding effect increased, and at 5000 rpm, the air over the cryostat began to rise slowly toward the ceiling. Particles of dust and smoke in the air made the effect clearly visible. The boundaries of the flow could be seen clearly and corresponded exactly to the shape of the toroid.

The weight of various samples decreased no matter what they were made from. Samples made from the same material and of comparable size, but with different masses, lost the same fraction of their weight. The best measurement gave a weight loss of 0.5% while the disk was spinning at 5000 rpm, with typical values ranging from 0.3 to 0.5%. Samples placed above the inner edge of the toroid (5-7 mm from the edge) were least affected, losing only 0.1 to 0.25% of their weight. The external boundary of the shielding cylinder was quite clear (no more than 2 cm). The maximum values of weight loss were obtained when the levitation height of the disk was at its maximum value, about 30-35 mm over the magnets. This condition cannot be reached above 70 K, although the disk had become superconducting already at 94 K.

During the time when the rotation speed was being decreased from 5000 to 3500 rpm, using the solenoids as braking tools, the shielding effect reached maximum values: the weight loss of the samples was from 1.9 to 2.1%, depending on the position of the sample with respect to the outer edge of the disk. These peak values were measured during a 25-30 seconds interval, when the rotational speed was decreasing to 3300 rpm. Because of considerable disk vibration at 3000-3300 rpm, the disk had to be rapidly braked in order to avoid unbalanced rotation, and further weight measurements could not be carried out.

The samples' maximum weight loss was observed only when the magnetic field was operating at high frequencies, on the order of 3.2 to 3.8 MHz. The following tables show how the shielding effect varied in response to changes in the disk's rotation speed or the current frequency.

At constant frequency of 2 MHz:

Rotation speed (rpm)	Weight loss (%)
4000	0.17
4200	0.19
4400	0.20
4600	0.21
4800	0.22
5000	0.23

At constant rotation speed of 4300 rpm:

Frequency (MHz)	Weight loss (%)
3.1	0.22
3.2	0.23
3.3	0.24
3.4	0.26
3.5	0.29
3.6	0.32

Remarkably, the effective weight loss was the same even when the samples, together with the balance, were moved upward to a distance of 3 m, but still within the vertical projection of the toroidal disk. No weight loss at all was observed below the cryostat.

We also observed a slight diminution of the air pressure inside the shielding cylinder. The difference between the external and the internal pressure was up to 5 mm of mercury in stationary conditions (disk rotating at 4000-5000 rpm) and increased up to 8 mm of mercury during the "braking" phase. Pressures were measured through a vacuum chamber barometer. We believe that the diminution of the pressure inside the shielding cylinder is originated by the pseudo-convective motion of the air, which being lighter tends to raise. This phenomenon is favoured by the fact that an entire cylinder of air get lighter at the same time and thus the ascending motion is amplified.

7 Discussion.

The interaction of a superconducting ceramic body with the gravitational field is a complicated process and cannot be characterized by one single law or physical phenomenon. Also, a comprehensive explanation of the mechanism responsible for high-temperature superconductivity has not yet been found. Still, these facts do not make the observed phenomenon less interesting.

In our previous work [4] the weight loss of samples over the levitating superconductor was smaller, varying from 0.05 to 0.3%. At that time it was difficult to exclude entirely any influence from the radio-frequency field because the sample was separated from the disk and the magnets by a thin plastic film. Now, the superconductor is situated in a stainless steel cryostat, so this influence should be negligible (see also Section 5).

The modification of the superconductor's crystalline structure produced a composite body with a dense and highly oriented upper layer and a porous lower layer with random grain orientation. The upper layer is superconducting at the operation temperature and is able to carry high J_c current under considerable magnetic field, while the lower layer cannot conduct high currents. The boundary between the two layers is likely to constitute a "transition" region in which the supercurrents, that are completely free to move in the upper layer, begin to feel some resistance.

It is also expected that a complex interaction between the composite ceramic body and the external magnetic field takes place. This interaction depends on the coherence length, the flux pinning, the field frequency and the field force, the penetration depth, and the parameters of the crystal lattice. These characteristics are interrelated in a complex way. According to the experimental data (compare also [10], where only a static field was applied), a levitating superconductor does not reveal any unusual shielding if it has no contact with the high frequency AC magnetic field.

As analyzed in [7, 8], pinning centers with different origins may exist inside the superconducting disk, and fluxes will be trapped at some of them. Fluxes trapped at weak centers will begin to move first, while those trapped at strong centers will not move until the Lorentz force exceeds the pinning force. The overall current will be composed of the superposition of flux motions with different speeds.

There are no grounds to claim that the rotation momentum of the disk interacts with gravitation force, but it seems that fast rotation is favorable for stabilization of the shielding effect.

Finally, it is worth noting that the experimental equipment described above has much in common with magneto-hydro-dynamic (MHD) generators.

The first attempt at a theoretical explanation of the effect has been offered by G. Modanese [11, 12]. Further investigations now in progress may help to prove, change, or complete the present understanding of the observed phenomenon.

8 Conclusions.

A levitating superconducting ceramic disk of $YBa_2Cu_3O_{7-x}$ with composite structure demonstrated a stable and clearly measurable weak shielding effect against gravitational force, but only below 70 K and under high-frequency e.m. field. The combination of a high-frequency current inside the rotating toroidal disk and an external high-frequency magnetic field, together with electronic pairing state and superconducting crystal lattice structure, apparently changed the interaction of the solid body with the gravitational field. This resulted in the ability of the superconductor to attenuate the energy of the gravitational force and yielded a weight loss in various samples of as much as 2.1%.

Samples made of metals, plastic, ceramic, wood, etc. were situated over the disk, and their weight was measured with high precision. All the samples showed the same partial loss of weight, no matter what material they were made of. Obtaining the maximum weight loss required that the samples be oriented with their flat surface parallel to the surface of the disk. The overall maximum shielding effect (2.1%) was obtained when the disk's rotational speed and the corresponding centrifugal force were slightly decreased by the magnetic field.

It was found that the shielding effect depended on the temperature, the rotation speed, the frequency and the intensity of the magnetic field. At present it seems early to discuss the mechanisms or to offer a detailed analysis of the observed phenomenon, as further investigation is necessary. The experimentally obtained shielding values may eventually prove to have fundamental importance for technological applications as well as scientific study.

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FIGURE CAPTIONS.

1. Schematic cross-section of the furnace for high-temperature treatment of the ceramic disk with planar hig-frequency inductors.
2. General magnets and cryostat setup.
3. Typical geometry and position of the disk over supporting solenoids.
4. Schematic design of rotating solenoids. a, b: various configurations.
5. Typical configuration of the tested set-up for the rotating solenoids.
6. Block scheme of the electrical connections.
7. Schematic design of the cryogenic system for the refrigeration of the superconducting disk.
8. General configuration of the equipment for the weight loss measurements.
9. Typical design of the three-point disk-braking system.

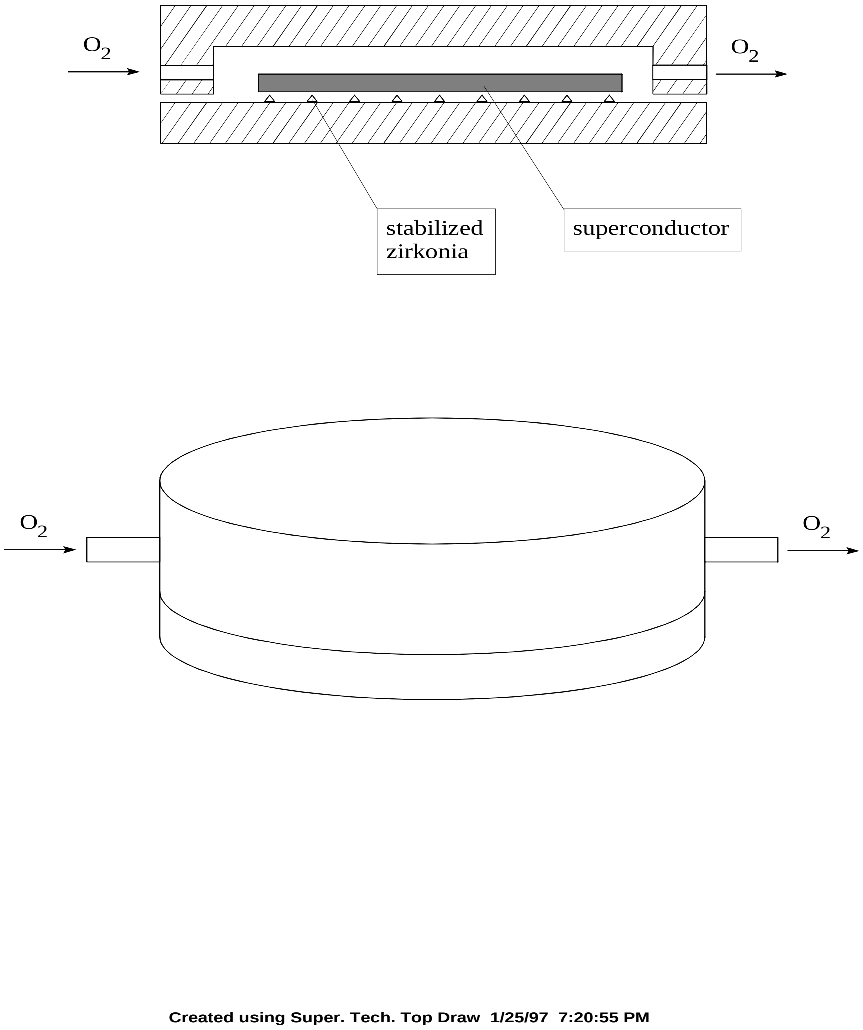
O2
O2
stabilized
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Fig. 1

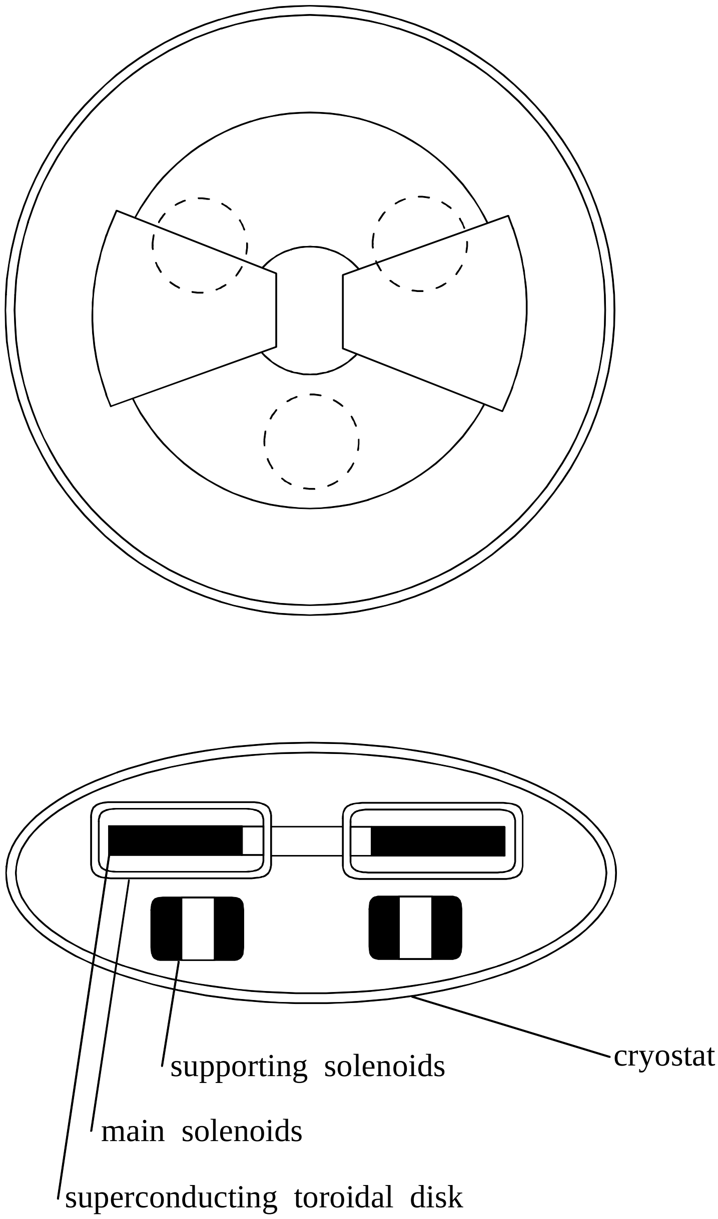

FIG.2

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Supporting solenoids

|general, fig. 21/5|

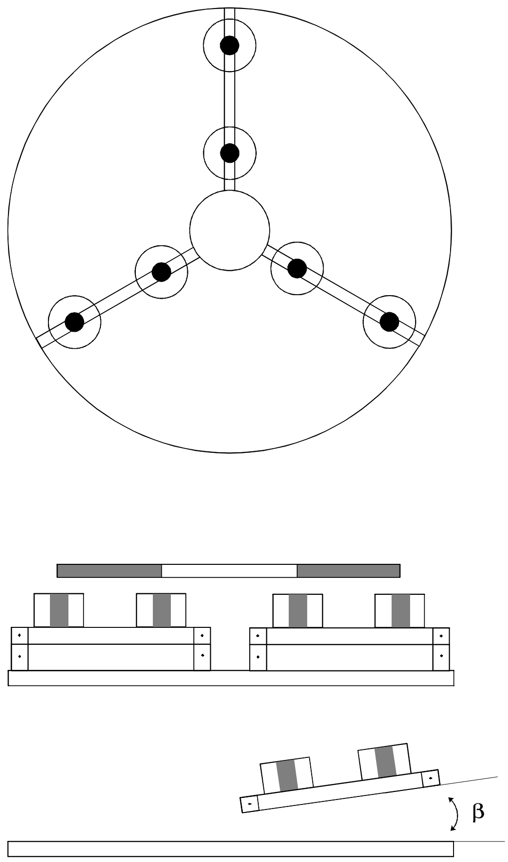

Fig. 3

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Rotating solenoids

|general, fig. 31/3|

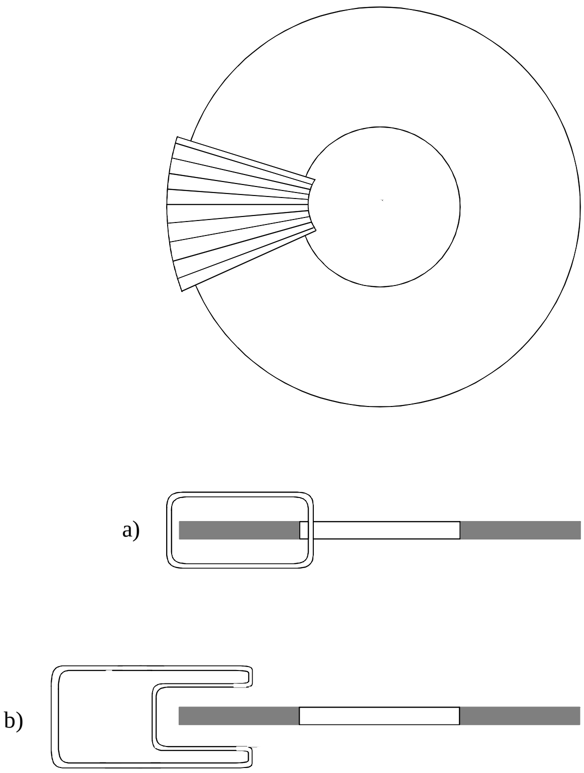

Fig. 4

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Rotating solenoids

|general, fig. 31/4|

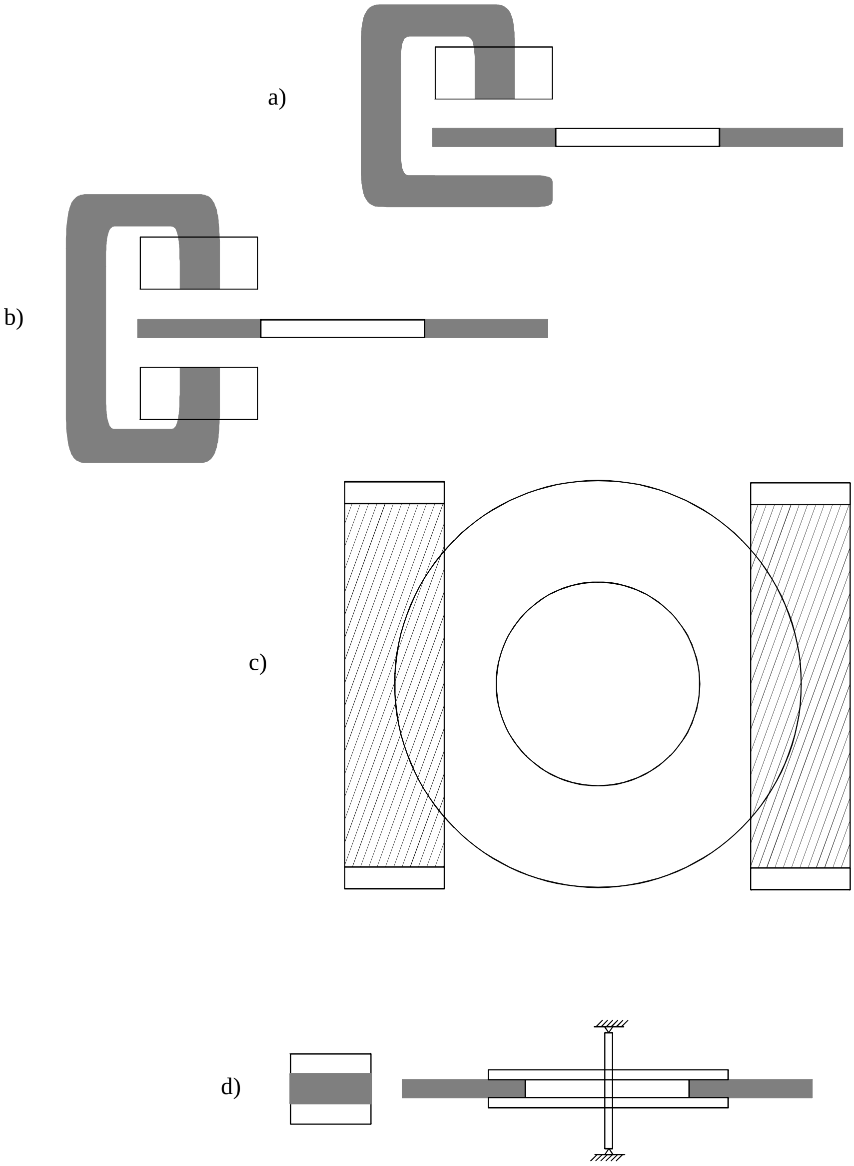

Fig. 5

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Electric circuits

|general, fig. 41/3|

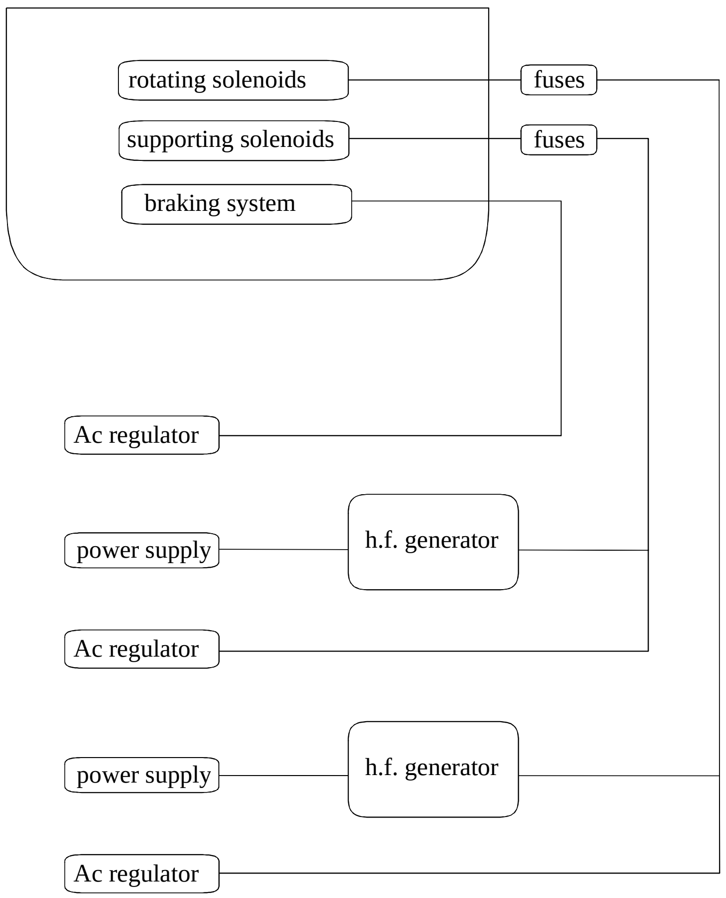

Fig. 6

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Cryogenic system

|general, fig. 51/5|

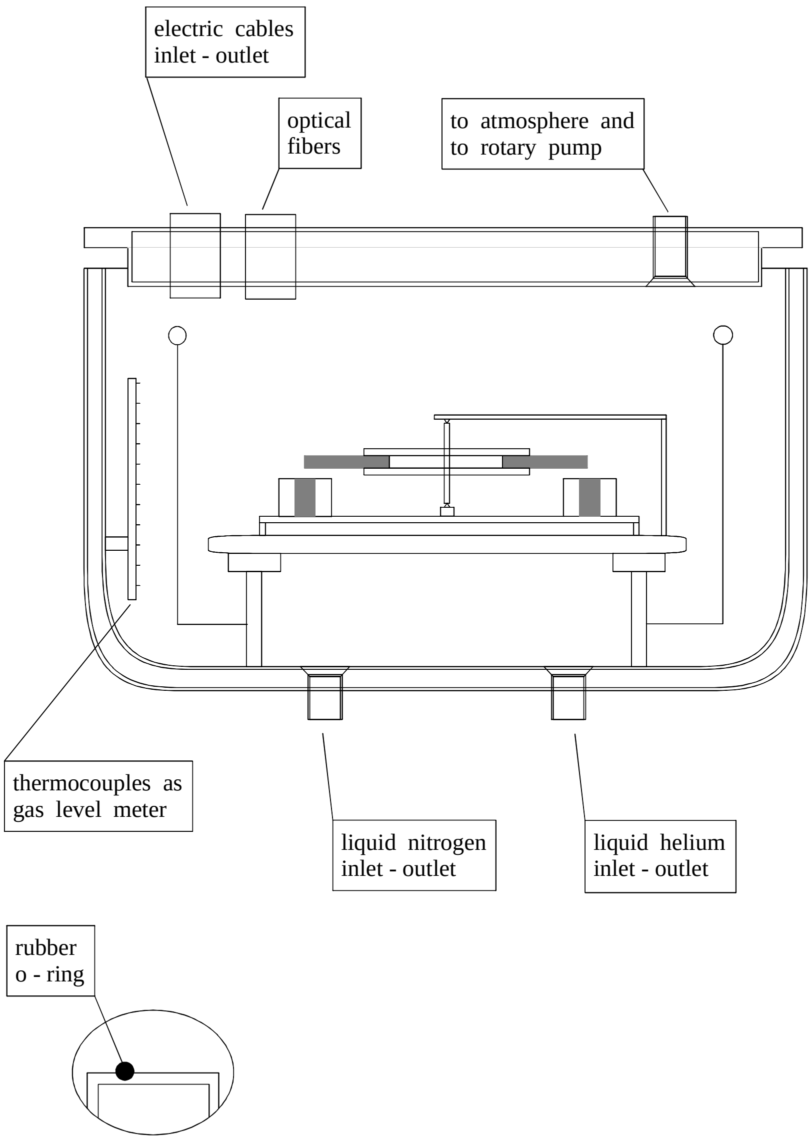

Fig. 7

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Weight & pressure measurements |general, fig. 61/4|

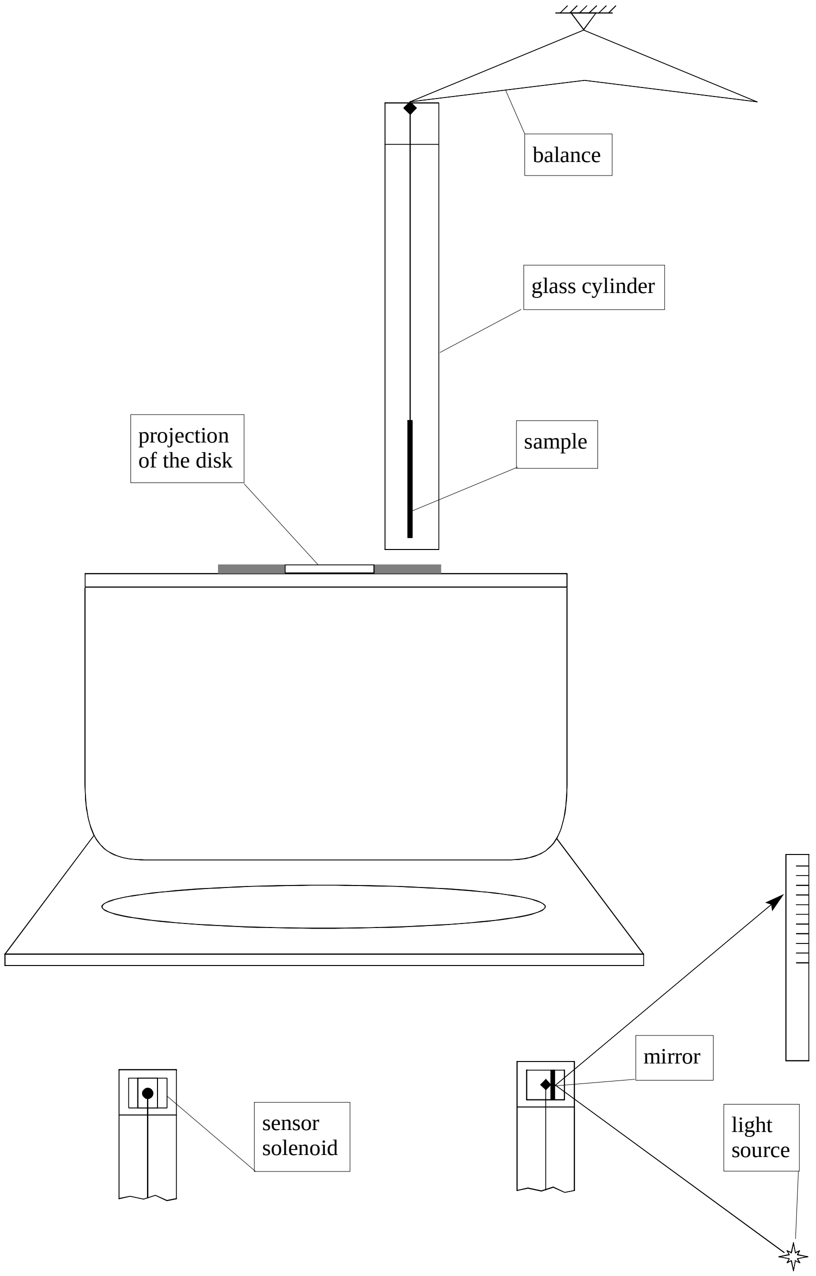

Fig. 8

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Disk braking system

|general, fig. 71/3|

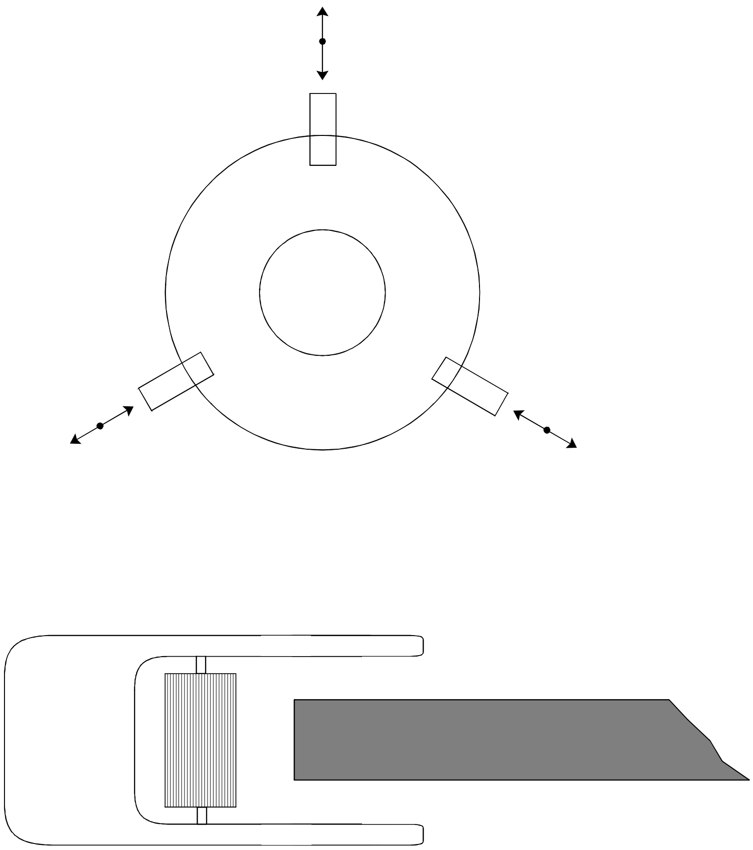

Fig. 9

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May 1995
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Theoretical Analysis of a Reported Weak Gravitational Shielding Effect.

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Abstract

Under special conditions (Meissner-effect levitation in a high frequency magnetic field and rapid rotation) a disk of high-T_c superconducting material has recently been found to produce a weak shielding of the gravitational field. We show that this phenomenon has no explanation in the standard gravity theories, except possibly in the non-perturbative Euclidean quantum theory.

04.20.-q Classical general relativity.
04.60.-m Quantum gravity.
74.72.-h High-T_c cuprates.

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In two recent experiments [1, 2], Podkletnov and co-workers have found indications for a possible weak shielding of the gravitational force through a disk of high-T_c superconducting material. In the first experiment a sample made of silicon dioxide of the weight of ca. 5 g, was found to lose about 0.05% of its weight when placed 15 mm above the disk. The diameter of the disk was 145 mm and its thickness 6 mm. The disk was refrigerated using liquid helium and was levitating over a solenoid due to the Meissner effect. When the disk was set in rotation by means of lateral alternating magnetic fields, the shielding effect increased up to 0.3%. When the disk was not levitating, but was placed over a fixed support, no shielding was observed.

In the second experiment the disk had the form of a toroid with the outer diameter of 275 mm and was enclosed in a stainless steel cryostat. Samples of different composition and weight (10 to 50 g) were placed over the disk and the same percentual weight loss was observed for different samples, thus enforcing the interpretation of the effect as a slight diminution of the gravitational acceleration. While the toroid was rotating (at an angular speed of 5000 rpm) the weight loss was of 0.3-0.5%, like in the first experiment, but it reached a maximum of 1.9-2.1% when the speed was slowly reduced by varying the current in the solenoids.

In both experiments, the magnetic fields were produced by high frequency currents and the maximum effect was observed at frequencies of the order of ca. 1 MHz. Measurements were effected also in the vacuum, in order to rule out possible buoyancy effects. The dependence of the shielding value on the height above the disk was very weak. Within the considered range (from a few cm to 300 cm) no sensible variation of the shielding value was observed. This weak height dependence is a severe challenge for any candidate theoretical interpretation, as it violates an intuitive vectorial representation of the shielding. We have analyzed in detail this issue in [3].

Independent repetitions of the experiment have already been undertaken, stimulated by scientific and especially technological interest. We would like to stress here the importance of precise measurements. In particular, it is essential to obtain exact spatial field maps and information about the transient stages. It is also crucial to use a different kind of balance from that used by the authors of [1, 2] and possibly a gravity gradiometer [4]. If the effect turned out to be of non-gravitational nature, its fundamental interest would be strongly reduced. On the contrary, if the effect is really a gravitational shielding its theoretical explanation calls for new and non-trivial dynamical mechanisms, as we argue in the following.

For clarity we shall organize our analysis as follows. Considering two masses m_1 and m_2 (which represent the Earth and the sample) and a medium between them (the disk), we shall evaluate their potential energy in these alternatives:

(1) the *medium* can be regarded as a classical system, as a quantum system, or as a Bose condensate with macroscopic wave function;

(2) the *gravitational field* can be regarded as classical or quantized, and in both cases as weak (perturbations theory) or strong.

In which of these approximations could a shielding effect arise? We can immediately observe that the possibilities of Point (1) are severely restricted by a large body of experimental evidence. Namely a sensible gravitational shielding has never previously been observed. Several experiments, starting with the classical measurements of Q. Majorana, have shown that the gravitational force is not influenced by any medium, up to one part in 10^{10} or less (for a very complete list of references see [5]). For a "classical" medium the reason for this is essentially the absence of charges of opposite sign which, by shifting or migrating inside the medium, might generate a field which counteracts the applied field. On the other hand when the medium is regarded as a quantum system, it is easy to check that the probability of a (virtual) process in which a graviton excites an atom or a molecule of the medium and is absorbed is exceedingly small, essentially due to the smallness of the gravitational coupling at the atomic level (see for instance [6]). It is then clear that the reported shielding can only be due to the Bose condensate present in the high-T_c superconductor.

Coming to Point (2), first we regard the gravitational field as classical. It is readily realized that in general neither the superconducting disk nor any other object of reasonable density, if placed close to the sample mass, can influence the local geometry so much as to modify its weight by the observed amount. To check this one just needs to write the Einstein equations (or even some generalizations of them) and impose suitable conditions on the source $T_{\mu\nu}$:

$$\begin{aligned} & R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -8\pi G T_{\mu\nu}; \qquad (1) \\ & G \sim 10^{-66}\ cm^2 \quad \text{in natural units;} \\ & |T_{\mu\nu}| < ... \end{aligned}$$

Let us be more explicit: according to Einstein equations any apparatus with mass-energy comparable to that of Ref.s [1, 2], if placed far away from any other source of gravitation, is unable to produce a gravitational field of the intensity of ca. 0.01 g †. The shielding effect, if

†When examining this possibility one should hypothesize that the disk produces a repulsive force. But it is known that arguments in favour of "antigravity" are untenable [7] and that local negative energy densities

true, must then consist of some kind of "absorbtion" of the Earth's field in the superconducting disk.

Having thus excluded any possibility of shielding for a classical gravitational field, we need now an expression for the gravitational potential energy of two masses m_1 and m_2 which takes into account quantum field effects, possibly also at non-perturbative level. This is given in Euclidean quantum gravity by the functional integral [13]

$$E = \lim_{T\to\infty} -\frac{\hbar}{T}\log\frac{\int d[g]\,\exp\left\{-\hbar^{-1}\left[S_g+\sum_{i=1,2}m_i\int_{-\frac{T}{2}}^{\frac{T}{2}}dt\,\sqrt{g_{\mu\nu}[x_i(t)]\dot{x}_i^\mu(t)\dot{x}_i^\nu(t)}\right]\right\}}{\int d[g]\,\exp\left\{-\hbar^{-1}S_g\right\}} \tag{2}$$

$$\equiv \lim_{T\to\infty} -\frac{\hbar}{T}\log\left\langle \exp\left\{-\hbar^{-1}\sum_{i=1,2}m_i\int_{-\frac{T}{2}}^{\frac{T}{2}}ds_i\right\}\right\rangle_{S_g}. \tag{3}$$

where S_g is the gravitational action

$$S_g = \int d^4x\,\sqrt{g}\left(\frac{\Lambda}{8\pi G}-\frac{R}{8\pi G}+\frac{1}{4}aR_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma}\right). \tag{4}$$

The R^2 term in S_g (important only at very small scale) is necessary to ensure the positivity of the action. The trajectories $x_i(t)$ of m_1 and m_2 are parallel with respect to the metric g; let L be the distance between them, corresponding to the spatial distance of the two masses. An evaluation of (3) in the non-perturbative lattice theory has ben carried out recently by Hamber and Williams [14].

In perturbation theory [15] the metric $g_{\mu\nu}(x)$ is expanded in the traditional way as the sum of a flat background $\delta_{\mu\nu}$ plus small fluctuations $\kappa h_{\mu\nu}(x)$ ($\kappa=\sqrt{8\pi G}$). The cosmological and the R^2 terms are dropped, leaving the pure Einstein action. Eq. (2) is rewritten as

$$E = \lim_{T\to\infty} -\frac{\hbar}{T}\log\frac{\int d[h]\,\exp\left\{-\hbar^{-1}\left[S_{\rm Einst.}+\sum_{i=1,2}m_i\int_{-\frac{T}{2}}^{\frac{T}{2}}dt\,\sqrt{1+h_{00}[x_i(t)]}\right]\right\}}{\int d[h]\,\exp\left\{-\hbar^{-1}S_{\rm Einst.}\right\}}, \tag{5}$$

where the trajectories $x_1(t)$ and $x_2(t)$ are two parallel lines in flat space. Expanding (5) in powers of κ one obtains to lowest order the Newton potential [13], and to higher orders its relativistic and quantum corrections [16].

are strongly constrained in Quantum Field Theory (see for instance [8]). There remains only the possibility of gravitomagnetic and gravitoelectric effects, which are however usually very small [9]. In [10] it is argued using the Maxwell-like approximated form of Einstein equations that the gravitoelectric field produced by a superconductor could be abnormally strong. In our opinion this conclusion contrasts with the full equations (2). For a comparison, consider the strength of the "gravitational Meissner effect": in a neutron star with density of about 10^{17} kg/m^3 the gravitational London penetration depth is ca. 12 km [11]. An experimental check disproving the hypothesis of a repulsive force is the measurement of g *below* the disk. Preliminary measurements [12] do not show any variation of g.

The Bose condensate composed by the Cooper pairs inside the superconductor is described by a bosonic field ϕ with non-vanishing vacuum expectation value $\phi_0 = \langle 0|\phi|0\rangle$. Using the notation $\phi = \phi_0 + \tilde{\phi}$, the action of such a field coupled to the gravitational field has the form

$$
\begin{aligned}
S_\phi = \textstyle\int d^4x \sqrt{g(x)} \quad & \left\{ \partial_\mu \left[\phi_0(x) + \tilde{\phi}(x) \right]^* \partial_\nu \left[\phi_0(x) + \tilde{\phi}(x) \right] g^{\mu\nu}(x) \right. \\
& \left. + \frac{1}{2} m^2 |\phi_0(x)|^2 + \frac{1}{2} m^2 \left[\phi_0^*(x)\tilde{\phi}(x) + \phi_0(x)\tilde{\phi}^*(x) \right] + \frac{1}{2} m^2 |\tilde{\phi}(x)|^2 \right\}, \quad (6)
\end{aligned}
$$

where m is the mass of a Cooper pair. In order to describe the interaction we insert S_ϕ into (2) and include $\tilde{\phi}$ into the integration variables, while ϕ_0 is considered as an external source, being determined essentially by the structure of the superconductor and by the external e.m. fields. In the following we shall disregard in S_ϕ the terms containing $\tilde{\phi}$, as they give rise to emission-absorption processes of gravitons which we know to be irrelevant.

Perturbatively, the interaction of $h_{\mu\nu}(x)$ with the condensate $\phi_0(x)$ is principally mediated by the vertex

$$
\mathcal{L}_{h\phi_0} = \kappa \partial_\mu \phi_0^*(x) \partial_\nu \phi_0(x) h^{\mu\nu}(x). \quad (7)
$$

This produces corrections to the gravitational propagator, which are however practically irrelevant, because they are proportional to powers of $\kappa \sim 10^{-33}\ cm$. It is straightforward to compute the corresponding corrections to eq. (5). We do not need to investigate in detail the signs of these corrections or their dependence from ϕ_0: they are in any case too small (by several magnitude orders) to account for the reported shielding effect.

Looking at the total action $S = S_g + S_\phi$ we recognize besides the familiar vertex (7) a further coupling between $g_{\mu\nu}(x)$ and $\phi_0(x)$. Namely, the Bose condensate contributes to the cosmological term. We can rewrite the total action (without the R^2 term for gravity) as

$$
S = S_g + S_\phi = \int d^4x \sqrt{g(x)} \left\{ \left[\frac{\Lambda}{8\pi G} + \frac{1}{2}\mu^2(x) \right] - \frac{R}{8\pi G} \right\} + S_{h\phi_0} + S_{\tilde{\phi}}, \quad (8)
$$

where

$$
\begin{aligned}
\frac{1}{2}\mu^2(x) &= \frac{1}{2} \left[\partial_\mu \phi_0(x) \right]^* \left[\partial^\mu \phi_0(x) \right] + \frac{1}{2} m^2 |\phi_0(x)|^2, \quad (9) \\
S_{h\phi_0} &= \int d^4x \sqrt{g(x)} \mathcal{L}_{h\phi_0} \quad (10)
\end{aligned}
$$

and $S_{\tilde{\phi}}$ comprises the terms which contain at least one field $\tilde{\phi}$ and are thus irrelevant, as we mentioned above.

We see from (8) that the condensate $\phi_0(x)$ and its four-dimensional gradient give a positive contribution to the intrinsic cosmological term $\Lambda/8\pi G$. It is known that a positive cosmological constant turns Eintein gravity into an unstable theory, as it corresponds in the action to a mass term with negative sign [15]. In the case we are considering here, the cosmological term is spacetime dependent. The situation is thus quite complicated and we shall just sketch it briefly in the following; a more complete account can be found in [17].

Since in any four-dimensional region Ω in which $\mu^2 > |\Lambda|/8\pi G$ the mass term of the gravitational field is non-zero and negative, in this region the field can grow without limit, at least classically (suppose to minimize the action (4) by trial functions which are vacuum solutions ($R = 0$), disregarding the R^2 term). In fact there will be some physical cut-off; thus within Ω the gravitational field will be forced to some fixed value, independent of the external conditions. This is similar to what happens in electrostatics in the presence of perfect conductors: the electric field is constrained to be zero within the conductors. In that case the physical origin of the constraint is different (a redistribution of opposite charges); but in both cases the effect on the field propagator turns out to be that of a shielding.

At this point we would need an estimate for both $|\Lambda|/8\pi G$ and μ^2. It is known that the cosmological constant observed at astronomical scales is very small; a typical upper limit is $|\Lambda|G < 10^{-120}$, which means $|\Lambda|/8\pi G < 10^{12}\ cm^{-4}$. To estimate μ^2 we can assume an average density of Cooper pairs in the superconductor of $\sim 10^{20}\ cm^{-3}$. Remembering that the mass of a pair is $\sim 10^{10}\ cm^{-1}$ in natural units, we find that $\phi_0 \sim 10^5\ cm^{-1}$ and thus $m^2|\phi_0|^2 \sim 10^{30}\ cm^{-4}$. If ϕ_0 varies over distances of the order of $10^{-8} \div 10^{-7}\ cm$, as usual in high-T_c superconductors, the gradient $(\partial\phi_0/\partial x)$ can be of the order of $10^{12}\ cm^{-2}$.

These values support our hypothesis that the total cosmological term is positive in the superconductor. Actually the positive contribution of the condensate is such that one could expect the formation of gravitational singularities in any superconductor, subjected to external fields or not – a fact which contrasts with the observations. This can be avoided if we take the point of view, supported by lattice quantum gravity with a fundamental length [14, 17, 18], that the effective intrinsic cosmological constant depends on the momentum scale p like

$$|\Lambda|G \sim (\ell_0 p)^\gamma, \tag{11}$$

where $\ell_0 \sim \kappa$ is the fundamental lattice length (Planck length) and γ is a critical exponent which up to now has been computed only for small lattices. The sign of Λ is negative. This provides a well defined flat space limit for the non-perturbative Euclidean theory based on the action (4), and ensures that the signs in our discussion of the minimization of the total action are correct.

We hypothesize that at the length scale of $10^{-8} \div 10^{-6}$ cm Λ could be of the same order of the average of μ^2, so that the competition between the two terms would lead to singularities only in those regions of the superconductor where the condensate density is larger than elsewhere. From this hypothesis we deduce that $|\Lambda| \sim 10^{-36}$ cm^{-2}, a value well compatible with the conventional experimental data at that scale ‡.

In conclusion, a shielding effect of the reported magnitude cannot be explained by classical General Relativity, nor by the usual perturbation theory of quantum gravity coupled to the Cooper-pair density $\phi_0(x)$ through the vertex (7). We have then considered a further possible coupling mechanism: the term $\mu^2(x) = [\partial^\mu \phi_0^*(x)][\partial_\nu \phi_0(x)] + m^2 \phi_0^2(x)$ in the condensate's action may act as a positive contribution to the effective gravitational cosmological constant. This may produce localized gravitational instabilities and thus an observable effect, in spite of the smallness of G, which makes the coupling (7) very weak. In the regions where the gravitational field becomes unstable it tends to take "fixed values" independent of the neighboring values. This reminds of the situation of electrostatics in the presence of perfect conductors. The effect on the field propagator and on the static potential is that of a partial shielding.

According to this picture, the magnetic fields which keep the disk levitating and rotating and produce currents inside it play the role (together with the microscopic structure of the HTC material) of determining the condensate density $\phi_0(x)$. The energy necessary for the partial "absorbtion" of the gravitational field is supplied by the high-frequency components of the magnetic field.

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‡It corresponds to a graviton mass of $\sim 10^{-18}$ cm^{-1} and thus to a (unobservable) range of gravity of $\sim 10^{18}$ cm. Note that a similar argument allows to restrict the exponent γ in eq. (11) to $\gamma > 2$. In fact, for $\gamma = 2$ we would have $|\Lambda| \sim p^2$, in contradiction with the fact that in order to be unobservable the range of gravity must be much larger than the length scale p^{-1} which we are considering.

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Proposal
for the

Experimental Detection of Gravitomagnetism in the Terrestrial Laboratory

By

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Abstract

A. Introduction

One of the predictions of the General Theory of Relativity, unveiled eighty years ago, is the existence, in a linear approximation, of a gravitational analog of the magnetic field, known as the gravitomagnetic (GM) or prorotational field. In the form of the Lense-Thirring Effect, this aspect of the gravitational field has been studied extensively since then. Indeed, there is a large-scale space mission, Gravity Probe-B, planned for launch near the turn of the millennium, designed to detect the exceedingly weak GM field of the earth.

It is the very weakness of the GM field of the entire earth that makes it so difficult, if not outright impossible, to measure the GM field in a terrestrial laboratory. Indeed, it has required extraordinary engineering ingenuity and precision to design gyroscopes sensitive enough to detect the 10^{-15} Hz precession induced by the earth at the orbit of Gravity Probe-B. Likewise, artificially generating a detectable GM field in the laboratory is clearly hopeless, though one of us (Becker) has elsewhere proposed a variant of a magnetic resonance experiment utilizing scanning probe microscopies and nanotechnologies, to attempt this.

The present experiment proposes to overcome the problem of the weakness of the GM field by taking advantage of the unique properties of macroscopically coherent systems such as superconductors (SC). It is by now well known that the magnetic flux threading a superconductor is quantized with a quantum number n. We will show that the GM field enters superconducting flux relations in the same manner as the magnetic field, and that the GM flux should also be quantized. Furthermore, if the value of magnetic flux quantum number is fixed for a given physical configuration, that same quantum number value governs the GM flux quantum as well. And this GM flux quantum, for sufficiently high n, should be macroscopically detectable. This experiment is designed to detect the GM field represented by this quantized GM flux.

One obvious question that must be asked is “If the GM field of even a body as massive as the earth is so tiny, how is it conceivable that a small SC can generate a field large enough to be readily measurable in the laboratory?” To address this, first note that in the presence of an external GM field, there is an additional GM term in the usual quantized magnetic fluxoid relation. This GM contribution to the magnetic flux is correctly taken to be negligible because the external GM field is so tiny.

Similarly, there is a magnetic term in the quantized GM flux relation. For substantial magnetic fields, such as those that would result in a high magnetic flux quantum n, this term is not small. Thus, a large GM flux quantum may be detected due to a magnetically induced GM field in the SC. The exact physical mechanism responsible for this "amplification" is still nebulous. One of the objectives of this experiment is to help elucidate such a mechanism. One of us (Becker, M.S. Thesis, Un. Alabama, Huntsville, 1994) has taken initial steps in identifying possible theoretical mechanisms.

It should be emphasized that a GM field large enough to be detectable in a terrestrial laboratory is predicted to occur only in macroscopic coherent systems such as superconductors or superfluids. (Though the effect should also occur in superfluids with a toroidal topology, the supercarriers in superfluids are much more massive than the electrons in SC, leading to a much smaller GM flux quantum than can be found in a SC.)

Ultimately, the effect to be studied, as with so many other unusual phenomenon, owes its postulated existence to the primacy of quantum mechanics, and the even more special properties of macroscopic, coherent systems.

Non-detection of the effect would actually raise equally important theoretical questions, such as: “If the Maxwell approximation to general relativity is correct, why is there not a GM flux quantum just as there is for the magnetic field?” After all, both vector potentials appear “symmetically” in the quantum mechanical canonical momentum. “Could the U(1) gauge field and topological description of the GM field in the Maxwell approximation be wrong, even if the Maxwell approximation to the Einstein equations is correct? What is the fundamental topological relationship between magnetism, GM, and rotation?”

B. Theoretical Background

B.1 Gravitomagnetism Background

Gravitomagnetism (also known as the prorotational field) is the gravitational analog of magnetism. The gravitational analog of the electric field is none other than our familiar Newtonian gravitational field, E_G. GM, on the other hand, has never been detected because it is so small. It is the result of general relativistic effects (GR) related to the curvature of space-time, and even the GM field of the entire earth is unimaginably weak. It can be visualized as the “dragging” of space-time by the rotating.

Despite the difficulties, there have been numerous experiment proposals for detection of GM over the last 30 years. The first one is still ongoing, Gravity Probe B, a spacecraft which will use an extraordinarily accurate and sensitive SC gyroscope to attempt to detect the GM field of the earth. Others exploit the properties of SC or superfluids (SF) to try to detect the earth's or laboratory generated fields. These have not, to the best of our knowledge, been carried out, because the predicted effects are still too minute to detect with current technology.

Though GM is not quite a new force of nature, it is nonetheless a new aspect of gravitation, and its detection would be regarded as extremely important to science, particularly if it can be done in a terrestrial laboratory.

An understanding of the expected physical effects of GM can best be gained by first revisiting electromagnetism. The ordinary electromagnetic (EM) magnetic flux density B (we will see why **B**, also called the magnetic inductance, is called the flux density; a related quantity, **H**, is called the magnetic field, but for our purposes will be regarded as one and the same) can be defined by its torque on a magnetic moment:

(1) $\mathbf{N} = \mathbf{M} \times \mathbf{B}$

where **N** is the torque and **M** the magnetic moment. Since torque is defined to be the time rate of change of angular momentum L, and since M is related L in many classical systems by

(2) $\mathbf{M} = (q/2mc)\mathbf{L}$

where q is the charge and m the mass of the particle, we can rewrite (1) as

(3) $d\mathbf{L}/dt = (q/2mc)\mathbf{L} \times \mathbf{B} = \mathbf{L} \times (q/2mc)\mathbf{B}$.

It is well known that (3) represents the precession of the angular momentum **L** about the direction of **B** at a Larmor frequency of

(4) $\Omega = -qB/2mc$.

Just as a spinning magnetic moment generates a magnetic field, solutions of the GR Einstein equations show that a spinning mass generates a dipolar GM field $\mathbf{B_g}$. In this case, the GM equivalent of the magnetic moment is the spin angular momentum **s**, so that the GM torque on a spinning body can be written as

(5) $\mathbf{N} = (1/2c)\mathbf{s} \times \mathbf{B_g}$.

Comparing (5) with (3) we conclude

(6) $d\mathbf{s}/dt = (1/2c)\mathbf{s} \times \mathbf{B_g} = \mathbf{s} \times (1/2c)\mathbf{B_g}$

and thus there is a GM precessional frequency of

(7) $\Omega_g = -B_g/2c$.

It is Ω_g which we will attempt to detect in our experiment. Unlike mechanical quantities, but like EM, both the dimensions of, and the equations for, $\mathbf{B_g}$ depend on the unit system chosen. In cgs, which is what will be used here, $\mathbf{B_g}$ has units of acceleration. In mks, it actually has units of frequency. Given this discordance, it will be best to translate final answers from one system of units to another rather than expressing the basic equations in several systems.

This frequency is a function only of the source field $\mathbf{B_g}$, and not of the nature of the test particle. The nature of the source field outside a spinning mass in a dipole approximation is such that

(8) $B_g = GS/2c^2r^3$,

where S is the spin angular momentum of the source body. This is similar to the dipole magnetic field outside a magnetized body.

Even for the earth, (8) is extremely small, on the order of 10^{-15} Hz at the surface.

Another similarity between EM and GM is in the Maxwell equations. In EM we can express **B** in terms of a magnetic vector potential

(9) $\mathbf{B} = \mathbf{curlA}$.

Similarly,

(10) $\mathbf{B_g} = \mathbf{curlA_g}$.

A Lorentz force equation also holds:

(11) $d\mathbf{v}/dt = \mathbf{E_g} + (\mathbf{v}/c) \times \mathbf{B_g}$.

A mass current generates a GM field just like a charged current generates a **B** field. One can also write down GM Maxwell equations, but we will not need them here.

B.2 Superconductors

SC have many curious characteristics. They are perfect conductors, so that once a current is started for any reason, it will continue. But they also obey the Meissner effect by which a magnetic field is excluded from the interior of a bulk SC, even in an applied **B** field. Physically, this comes about because the **B** field induces surface (not bulk) currents, which set up a field opposing the applied field in the interior; the net field is B=0. These currents only flow in a layer, the London penetration depth, in which **B** and the current **J** fall-off exponentially with distance into the SC.

All the strange properties of SC ultimately derive from the quantum mechanical (QM) state of the system. Below a certain critical temperature, it becomes energetically favorable for conduction electrons in the material to form pairs such that their center of mass momentum is zero; these are Cooper pairs. At absolute zero, all the electrons in the SC form Cooper pairs, and so condense into the same QM state of zero momentum.

Since electrons have QM spin of 1/2, and since opposite spin electrons are paired, a Cooper pair is QM object of integral spin,called a boson. Unlike fermions, which obey the Pauli Exclusion Principle, any number of bosons can occupy the same QM state. So below the critical temperature, T_c, the SC can be said to be in a macroscopically occupied QM state. In order to change the state, a physical phenomena would have to break all the Cooper pairs and remove the electrons from this state, known as a condensate. This requires much more energy than just breaking a single Cooper pair, and so changing QM states becomes exceedingly unlikely.

This explains properties like persistent currents. They persist, because once the QM state is set-up, it can't easily be changed. There are complications to the simple picture just described. For example, persistent London screening currents must be generated by an applied field, and then the Cooper pairs do not have zero center of mass momentum. But they do have zero QM canonical momentum, which is the correct vanishing quantity in this case.

At T>0, not all electrons form Cooper pairs, but the ground state is still macroscopically occupied. For our purposes, this will suffice. Another complication is the existence of several types of SC. The first to be discovered was Type I SC, which obey the Meissner effect for all B and all $T<T_c$. Next came Type II SC, which obey the Meissner effect only for B<Bc1, the Lower Critical Field. Between B_{c1} and a B_{c2} (Upper Critical Field), an applied magnetic field can penetrate the SC and form current vortices around the field lines. Finally, there are the famous high-T_c SC, which we will actually use. High-T_c SC do not obey the same microscopic QM theory as do standard Type I and II SC (s-wave BCS theory), but for our purposes can be regarded as Type II SC: they have a B_{c1}. We shall actually be interested in the Meissner regime of the Type II SC.

In the Type II regime, the critical property is that the magnetic field can penetrate in a vortex. The vortex core is not SC, and is composed of normal material, that is, electrons not paired into Cooper pairs. Topologically, this has enormous importance, because it means the SC material is no longer simply-connected; it now has a hole in it. The same thing can happen to any SC if one drills a hole into an otherwise bulk SC, creating a ring or doughnut shaped object.

Whereas screening, diamagnetic, currents are always set-up around the outer periphery of a SC to cancel an applied field in the interior, if a hole is present, another current, called the paramagnetic current, is set-up around the inner circumference of the hole. The paramagnetic current ensures that once a SC is cooled below T_c in an applied field, the magnetic flux penetrating the hole remains constant even if the applied field is removed. And this flux through the hole obeys a quantization condition. It is this condition, when amended by GM, which our experiment will investigate.

B.3 SC Fluxoid Quantization

To see where these conditions come from, we can delve into QM briefly. A Cooper pair moving in an external magnetic field of vector potential **A** has a momentum given not by the ordinary momentum m**v**, but by the canonical momentum

(12) $\mathbf{P} = 2m\mathbf{v} + 2q\mathbf{A}$.

Note that **A** is an external or applied potential on, not the field generated by this moving charge, q. In QM, any particle can be represented by a wavepacket, and if the particle has a finite momentum, the wavepacket will also have finite wavelength. This means there will be a phase change across the wavepacket as the particle moves by, just as the phase of a sine wave sweeps from 0 to 2π as it moves past. The phase change is proportional to the line integral of the canonical momentum. Over a closed path, this must be $2\pi n$, where n is the number of times around the path. Recognizing that in a SC, the supercurrent **J** is proportional to the (ordinary) momentum of the Cooper pairs of charge 2e and mass 2m, we have

(13) $2\pi n = (4\pi m/hde)\int \mathbf{J}\bullet d\mathbf{l} + (4\pi e/h)\int \mathbf{A}\bullet d\mathbf{l}$

where h is the Planck constant and d in the denominator is the SC number density, while dl denotes a line integral around a closed contour. This is the Phase

Quantization condition. We can apply the Stokes theorem for vectors related by (9),

(14) $\int \mathbf{A}\bullet d\mathbf{l} = \int \mathbf{curlA}\bullet d\mathbf{a} = \int \mathbf{B}\bullet d\mathbf{a}$,

to (13), where d**a** denotes a surface integral over a closed contour. If we also divide both sides of (13) by $4\pi e/h$, we obtain

(15) $nh/2e = n\Phi = (m/de^2)\int \mathbf{J}\bullet d\mathbf{l} + \int \mathbf{B}\bullet d\mathbf{a}$

This equation defines the Magnetic Fluxoid Quantum Φ on the LHS. The LHS is called the fluxoid rather than the flux because it is the sum of a flux term and another term. Since the first term on the RHS is a line integral, and since the current **J** vanishes deep inside the SC, for any contour in the bulk SC, this term can be neglected, and we can say that the magnetic flux, defined by the second term RHS, is quantized.

Notice that it is the flux that is quantized, not the field.

Mathematically, the vanishing of the first term of (15) makes perfect sense. However, it is a little more difficult to interpret in terms of physical measurements. To do that, we will rewrite the first term by the Stokes theorem (14) to obtain

(16) $nh/2e = n\Phi = (m/d^2)\int \mathbf{curlJ}\bullet d\mathbf{a} + \int \mathbf{B}\bullet d\mathbf{a}$

The screening layer with the current is contained in the surface integral when the contour is in the bulk SC, so we interpret (16) to mean that an experiment measures the TOTAL magnetic field due to the flux through the hole (2nd term) PLUS the magnetic flux generated by the London current layer around the hole (1st term). (In a SC, **curlJ** is proportional to magnetic field.) Since that screening current is precisely the current necessary to establish and maintain the flux through the hole at a quantized value according to theory, experiments confirmed the theory when they detected a quantum of flux given by the LHS. Indeed, if the applied field had a flux of, say, $(n+1/4)\Phi$, a current is set up to move the trapped flux in the hole to an even quantized value of $n\Phi$. There is also a very small magnetic flux contribution from the penetration of the external field into the London layer around the hole (from which it is not screened, unlike the rest of the SC). This would show up as a slight deviation from the quantized value.

If the SC is very thin, such that its thickness is no greater than the penetration depth, effectively, there is no bulk SC, and the contour goes right through the London layer around the hole. The interpretation of this in light of (16) is that the London current layer is no longer inside the integration surface area and so cannot contribute. Therefore, the only term left is the 2nd, with the result that a measurement now sees a deficit in the flux, since the 1st term has effectively been excluded. This deficit was also observed in experiments.

B.4 GM Quantization

The importance of the discussion in the last section is that the GM field simply adds another term to the RHS of each of the equations in that section. Therefore, if what is quantized and measured is the SUM of ALL terms on the RHS, there is, a good chance for some sort of GM quantum which could be measured.

To include the contribution of GM, one need only add appropriate terms of $2m\mathbf{A_g}/c$ or $2m\mathbf{B_g}/c$ to equations (12-16). The phase equation becomes

$$(17)\quad 2\pi n = (4\pi m/hde)\int \mathbf{J}\bullet d\mathbf{l} + (4\pi e/h)\int \mathbf{A}\bullet d\mathbf{l} + (4\pi m/ch)\int \mathbf{A_g}\bullet d\mathbf{l}$$

and the magnetic fluxoid equation,

$$(18)\ nh/2e = n\Phi = (m/de^2)\int \mathbf{curlJ}\bullet d\mathbf{a} + \int \mathbf{B}\bullet d\mathbf{a} + (m/ec)\int \mathbf{B_g}\bullet d\mathbf{a}.$$

If our interpretation in the last section holds up, we can expect the 3rd term of (18) to make a contribution to the measured magnetic flux such that the total for a bulk SC is the LHS. This term will be extremely small, not only because the applied GM is so small, but because m is the mass of an electron.

Now we may use the phase equation (17) to obtain a GM fluxoid relation by dividing both sides by ($4\pi m/ch$):

$$(19)\quad nhc/2m = (c/de^2)\int \mathbf{curlJ}\bullet d\mathbf{a} + (ec/m)\int \mathbf{B}\bullet d\mathbf{a} + \int \mathbf{B_g}\bullet d\mathbf{a}.$$

We have transformed the quantization relation into a form for which the LHS has dimensions of GM-flux (that is, acceleration-flux in cgs). Carrying over the interpretation of the previous section, we interpret the RHS as being the total GM flux in the system, which is quantized. The first term is that GM flux from the moving currents in the London layer; the third term is the "pure" GM flux from the external field; the second term we interpret to be the GM flux induced by the applied magnetic field. Note that the GM quantum number is the same as the magnetic one for the same physical situation. Quantization of one establishes the other. And we could have just as easily reversed the process by deriving the GM flux quantization relation from the phase quantization relation first, and then derived the magnetic flux quantization relation from the GM relation.

Since the third term is so small, the important question is whether the interpretation of the second term is valid; this term will not be small in general, if for no other reason than the factor of 1/m is so large. Objections can be made to the concept that the entire RHS is measurable on the grounds that there is no known mechanism to explain the size of the second term if it is understood to be an induced GM field. Exotic mechanisms can be imagined, such as coupling of the magnetic and GM field lines through the topology of vortices, perhaps via a form of coherent zero point motion (Becker, Thesis, UAH 1994; or the possibility that it might be ions that are also responding to the GM field, in which case m would be at least 7500 times larger than the electron mass entered in the above equations. Another interpretation is that the second term represents the acceleration-flux induced by the magnetic field that could be felt by a magnetic body, if one were present. In this case, the RHS would not be entirely GM in origin. However, this last interpretation is not consistent with the interpretation of the GM term in the magnetic fluxoid as a GM induced magnetic field. All these ideas are pure speculation, however.

So the experiment hinges on that second term: if it does not physically contribute to a GM flux, then the other two terms are far too small to be measurable. On the other hand, if the three terms and the fluxoid itself are GM, the effect may be very large and definitely noticeable given the right circumstances.

B.5 GM Experiment Concept

The actual experiment consists of suspending a small high-T_c SC from a balancing-torsion mechanism akin to that used in the Cavendish experiment. A hole is scooped out of the bulk SC, such that a small, rotating cylinder of non-magnetic material can be placed inside. The cylinder has its long axis oriented in the horizontal plane, and spins along that axis.

The cylinder is supported by a mechanism which allows rotation around the long axis, but resists rotation around any other. The SC itself, immersed in liquid nitrogen, is free to rotate in the horizontal plane. Cylinder rotation is maintained by a small gas jet. There is a small mirror or other such rotation sensor on the SC suspension assembly.

The SC is projected to be a YBa2Cu3O7 compound, a high Tc, Type II SC, with T_c=90-98°K, and a lower critical field H_{c1} = 200G. Its configuration might be in the realm of 23mm in diameter and 4mm in thickness. The hole size will have to be chosen, in part, by considerations of fitting the cylinder suspension apparatus inside.

Before the hole is drilled into the SC, it will be tested to see if there are any detectable GM effects when the SC is magnetized above the lower critical field, whereupon vortices may enter the SC. Each vortex has n=1, which may produce a torque in its vicinity which can be calculated from the equations in section B.6.

If a strong enough total GM fluxoid quantum is present in the hole, due to a large applied magnetic field, the cylinder ought to precess about an axis perpendicular to the horizontal plane. However, the cylinder is constrained from precessing by the fixture which holds it in place against the air stream. Since the SC to which the cylinder is, we believe, coupled by virtue of the GM field, is free to rotate in the precession plane, the cylinder's precessional angular momentum is transferred to the SC, which twists about its suspension, permitting a measurement of the degree of turn from the sensor on the suspension. Alternatively, a direct measurement of the cylinder’s precession can be attempted.

To calibrate the apparatus and ensure that there are no lingering magnetic effects in the cylinder, the cylinder set-up experiment should first be run with no SC present, with just the applied field. Next, the experiment should be repeated with the SC, but at a $T > T_c$, where there should be no quantization effects. Finally, the full SC plus cylinder tests can be run, varying the applied magnetic field as desired, as well as other parameters. A magnetized cylinder should be substituted for the non-magnetic test body, not only to verify the basic experimental set-up, but in case no GM effect is seen, to verify that an experimental effect is present even in the well known case of the SC magnetic field.

B.6 Experiment Calculations

In this section we will outline the calculations needed to compute the forces that are expected to arise from the GM-induced precession of the cylinder based on the theory of section B.4 is correct.

For a given applied magnetic field, the fluxoid quantum number is obtained from

(20) $n = \pi r^2 H/2.07\text{x}10^{-7}$

where H is the applied field, r is the radius of the hole and the magnetic fluxoid quantum has the value $2.07\text{x}10^{-7}$ Gcm^2. Since n is an integral quantum number, it should be rounded to the nearest integer.

Since it is believed that the GM field can penetrate the SC, unlike the magnetic field, the area that enters the GM fluxoid is that of the whole SC, not the hole. From the LHS of (19) we estimate the GM field as an average over its penetration area. This may just be an estimate because, at least in the case of the magnetic field, the field is not uniform in a flat cylindrical SC as will be used for this experiment. Conversely, if the GM field is not expelled from the bulk SC, its lines should not deviate from linearity to any degree, making the average field estimate from the GM flux a better estimate than one for **B** itself.

(21) $B_g = (nhc/2m)/\pi R^2 = (Hhc/2m)(r/R)^2/2.07\text{x}10^{-7}$

where R is the radius of the SC.

If B_g is given by (21), the precession velocity of the cylinder is therefore

(22) $\Omega = B_g/2c = (Hh/4m)(r/R)^2/2.07\text{x}10^{-7}$.

The torque the GM field will attempt to apply to the cylinder so as to result in the precession velocity (22) is given by (6):

(23) $\mathbf{N} = \mathbf{s} \text{ x } \mathbf{B_g}/2c = \mathbf{s} \text{ x } (\mathbf{H}h/4m)(r/R)^2/2.07\text{x}10^{-7}$.

Rigid body spin angular momentum is given by

(24) $\mathbf{s} = \mathbf{I}\boldsymbol{\omega}$

where ω is the spin angular velocity (not the same as Ω). A cylinder rotating around its long axis has moment of inertia I of

(25) $I = M\alpha^2/2$

where M is the mass of the cylinder and α is its radius. Putting both (24) and (25) into (23), we obtain (assuming right angles)

(26) $N = (M\omega\alpha^2/2)(Hh/4m)(r/R)^2/2.07\text{x}10^{-7}$.

Collecting factors, (26) can be rewritten as

(27) $N = (M\omega Hh/8m)(r\alpha/R)^2/2.07\text{x}10^{-7}$.

Since the cylinder will be fixed in the precessional rotation direction, but the SC will be free, the back coupling of the cylinder to SC should transfer the applied torque to the SC, resulting in the torque, and therefore force, on the SC suspension mechanism. The torque is given by (assuming right angles)

(28) $\mathbf{N} = \mathbf{R} \times \mathbf{F}$.

So, assuming right angle relative to the apparatus,

(29) $F = N/R = (M\omega Hh/8Rm)(r\alpha/R)^2/2.07\text{x}10^{-7}$.

We can also write the force equation in terms of n, the quantum number, by reinserting (20) into the RHS of (29):

(30) $F = (nM\omega h/8\pi Rm)(\alpha/R)^2)$.

For the following suggested estimated parameter values

M - Mass of Test body - 2.0 g
w - Angular velocity of Test body - 10.0 rad/s
R - Radius of SC - 0.11 cm
r - Radius of SC hole - 0.05 cm
α - Radius of Test Body - 0.03 cm
m - Electron mass - 9.11×10^{-28} g
h - Planck Constant - 6.63×10^{-27} erg•s

the ratio of force to quantum number is

(31) $F/n = 3.916$ dynes/n.

The value of n at the lower critical field (200 G) for the material proposed for this experiment, with r as above, is from (20)

(32) $n = 7.58 \times 10^6$.

This would make the force

$F = 2.97 \times 10^7$ dyne!

For a more reasonable magnetic field, like the earth's (0.3 G) we get

$n = 1.14 \times 10^4$ dyne

and the force is

$F = 4.46 \times 10^4$ dyne.

It is essential to use small-area holes in the SC. While it is the flux which is quantized, it is the field which induces the precession. Too large a hole means that the flux can be dominated by the hole area, rather than the field, with the result that precessional effects could be quite small, despite a large applied magnetic field. Conversely, it is not quite customary to suspend small test bodies in small holes in SC, which may explain why these effects have not been noticed before.

C. Experiment Design

The proposed experiment concept is a combination of a variant of the classical Cavendish experiment for the measurement of the gravitational constant G, and the classic experiments demonstrating the quantization of magnetic flux in SC systems.

The Cavendish-like assembly will be designed to detect even small torques induced by the GM field in a high-density cylinder rotating inside a SC toroidal ring in the superconducting regime in trapped magnetic flux (see Fig. TBD). A persistent (paramagnetic) supercurrent can be established by lowering the temperature of a SC through the critical temperature in an applied magnetic field, and then removing the field. Quantized magnetic flux through the toroidal hole in the SC is thereby also established. For ease of experimental design and operation at liquid nitrogen temperatures, the SC is chosen to be a High Tc ceramic oxide (TBD), operated in magnetic fields below its lower critical field of (TBD) to avoid the complication of flux vortices being induced in the SC.

The SC and the rotating cylinder are enclosed in a liquid nitrogen dewar made of transparent Pyrex glass about 1.0 m high and 0.15 m in diameter (see Fig. TBD). The dewar has two standard cryogenic silvered walls with a vacuum between them to insulate the liquid nitrogen inside from the external environment. The dewar has a vertical slit of un-silvered glass to permit some viewing of the interior.

A clear Pyrex glass vacuum chamber approximately 0.9 m high and 0.10 m in diameter is gently lowered by a manipulating mechanism into the dewar filled with liquid nitrogen. It has a vacuum flange at the top to permit the removal of a vacuum lid through which electrical wires and the manipulator arm pass to facilitate adjustments inside the chamber under cryogenic and vacuum conditions. Gas may be pumped out of the vacuum chamber through the vacuum lid with the aid of a high quality mechanical pump. Pressure in the chamber can be lowered to a fraction of a torr, thus reducing extraneous torques on the apparatus in the chamber due to convective flows. Helium or hydrogen gas jets can be passed in a highly controlled manner through the vacuum lid. These jets exert micro-torques on components of the apparatus in the chamber. The temperature inside the vacuum chamber are monitored via thermocouples.

Hanging from the vacuum lid is a thin and narrow flat strip of non-magnetic metal as in a Cavendish Gravitational Balance. Hanging on the end of the metal strip is a pure teflon yoke holding a pure glass rod which passes through holes in the yoke, so that the rod can turn freely with minimal friction, but without sliding back and forth in the yoke.

Centered on the glass rod, and concentric with it, is a precision cylinder (dimensions TBD) made of a high density substance. The dense cylinder is free to rotate at high speed around its axis with very little friction. It rotates precisely along one of the principle axes of its moment of inertia.

To act as experimental controls, eliminating the possibility of extraneous magnetic effects in the cylinder, and for experiment operation above Tc, where there should be no macroscopic GM effect, cylinders of different compositions, but similar mass properties, will be capable of being changed out. The GM effect should be invariant to changes in cylinder composition, so long as the mass properties are kept the same, and so a variety of cylinder compositions will be used: relatively non-magnetic materials such as copper, lead, cesium, lead-glass, gold, silver, platinum with permeability TBD; paramagnetic materials such as TBD; and ferromagnetic materials such as iron, nickel, or magnetic composites (permeability TBD). Cavendish Balance measurements of any induced torques will be made at non-cryogenic temperatures, under external magnetic fields resulting in a flux equivalent to that which will be trapped in the SC, to calibrate and characterize the behavior of the sample cylinders in applied magnetic fields.

Pointed horizontally at the upper and lower surfaces of the cylinder, and from opposite sides of the cylinder, are four micro-tubes blowing helium or hydrogen gas against the cylinder, inducing it to spin in both possible directions without exerting on it any significant net force or torque parallel to the vertical axis. Opposite each of the four flow tubes is a "getter funnel" through which the gas which has just passed the cylinder is caught and pumped out.

There is a safety catch to hold the yoke securely any time the vacuum chamber is moved. The catch very gently releases the yoke once the vacuum chamber is securely in position. There is TBD provision for reducing the amplitude of any accidental oscillations of the yoke to zero by use of tiny jets of helium gas blowing against the yoke from opposite sides. The jets exert tiny, controlled torques of reversing sign applied out of phase with the yoke's natural frequency oscillations about the vertical axis. When not in use, the jets will be secured so as not to leak and exert accidental torques. Accidental vibrational and impulsive (bump) disturbances will also be minimized by TBD.

Potential thermal gradients in the vacuum chamber due to boil-off and heat influx can be reduced by first pumping-down the liquid nitrogen to a temperature below the atmospheric pressure level boiling point, and then letting the pressure build up as the temperature rises.

Visibility into the chamber can be temporarily increased by countering potential thermal gradients by the introduction of thermal baffles which can be raised and lowered into the chamber, alternatively covering and uncovering the silvered and non-silvered portion of the vacuum chamber. The baffles might include many cylindrically concentric thin silver cylinders surrounding the vacuum chamber held together by thermally insulating spacers at separations of about 1.0 mm. Under conditions of thermal equilibrium they would help to keep heat energy from radiating into the vacuum chamber through the un-silvered portions of the dewar.

Using helium or hydrogen gas jets, the high density cylinder spins with its horizontal axis passing through the hole in the SC ring around which the supercurrent flows. While maintaining the basic toroidal topology, the SC could be varied in thickness from disk-like to cylinder-like. The latter, more solenoidal, dimensions may be preferable for ensuring uniformity of magnetic field lines, and presumably GM field lines, in the hole.

The SC ring is rigidly attached to the vacuum lid so any torque which may be exerted on the cylinder will be associated with a reaction in the SC, causing the yoke suspended from the metal strip to rotate around the vertical axis.

A convex mirror of about 2.0 m focal length is mounted on the teflon yoke holding the cylinder and reflects a horizontal beam from an external laser (the beam of which passes into and out of the vacuum chamber and liquid nitrogen dewar through the optically smooth glass surface). The horizontally reflected/focused beam lands as a point of light on a millimeter scale about 2.0 m away. Any significant rotation of the yoke and cylinder will cause shifts in the position of the light focus of more than 0.1 mm.

Three external Helmholtz coils are oriented so as to cancel the ambient magnetic field of the earth to below 0.1% of its normal value in three orthogonal directions, and are used to apply the external magnetic fields resulting in the quantized magnetic flux. Magnets of TBD-type are used to apply the external magnetic fields leading to the quantized magnetic flux. The apparatus can be placed in a standard TBD-cage to minimize unwanted magnetic fields of external origen when it is so desired.

The experimental apparatus will be pre-calibrated for sensitivity to Newtonian torques exerted by nearby mobile masses in the laboratory. Since these torques can also be generated by the presence of human experimenters, an experimental protocol will be designed to minimize any such disturbance.

While the various sources of disturbance torques are postulated to be significantly lower magnitude than the predicted GM induced torques in strong magnetic fields, differential and resonance torsional measurement can be employed to further reduce any contamination.

Flexibility in the experiment design is sufficient to permit variations in the following experimental parameters:

1. The axis of the SC can be moved smoothly and without induced vibrations in or causing collisions between the rotating cylinder and the SC. This can be done under cryogenic and vacuum conditions.

2. The speed and direction of cylinder rotation can be changed by varying the directions and flow rates of the helium or hydrogen jets directed at the top and bottom of the cylinder, under cryogenic and vacuum conditions.

3. The magnitude of the trapped magnetic flux can be adjusted after each run of the experiment sequence by changing the applied magnetic field.

4. The composition of the cylinder and its mass properties (e.g. moment of inertia) are adjustable by switching out cylinder samples.

The following Tables illustrate schematically the way parameter space can be scanned to test whether there is or is not a macroscopic quantized GM flux separate and distinguishable from magnetic flux. In Table 1, it is assumed there is an applied magnetic field equivalent to some integer multiple of the magnetic flux quantum. In Table 2, it is assumed that some non-integer (say, n+1/4) of the magnetic flux quantum is applied. Each entry in the Tables contains an “equivalent” magnetic (for a magnetic test body) or GM (for a non-magnetic test body) flux strength that would be felt by the test body as a torque, in the different temperature regimes. If there is no macroscopic GM flux in the superconducting regime, then all entries in the second column would be zero in both Tables.

	Magnetic Test Body	**Non-magnetic Test Body**

T < Tc	**n**	**n**
T > Tc	**n**	**0**

Table 1: Integer Quantized Applied Magnetic Flux

	Magnetic Test Body	**Non-magnetic Test Body**
T < Tc	**n**	**n**
T > Tc	**(n+1/4)**	**0**

Table 2: Non-integer Quantized Applied Magnetic Flux

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Gravitational Meissner Effect

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Abstract

The gravitational analogue of the electromagnetic Meissner effect is investigated. Starting from the post-Newtonian approximation to general relativity we arrive at gravitational London equations, predicting a gravitational Meissner effect. Applied to neutron stars we arrive at a London penetration depth of 12km, which is about the size of a neutron star.

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I Introduction

There is strong evidence that neutron stars are superfluid and maybe superconducting [1], indicating that macroscopic quantum effects play a significant role in neutron stars. In addition neutron stars are very strongly gravitating objects. We therefore would like to investigate the possibility of macroscopic quantum gravity effect in the form of a gravitational Meissner effect.

In the post-Newtonian approximation Einstein's theory of general relativity, gravity looks like a U(1) theory and is very similar to the electromagnetic Maxwell theory [2]. This allows us to follow closely the approach of London [3, 4] in deriving gravitational London equations, predicting a gravitational Meissner effect. Not knowing the underlying microscopic theory of quantum gravity we have to resort to this semi-classical approach. We find the gravitational London penetration depth to be about 12 km for a typical neutron star of radius 15 km. Furthermore, as the density of the neutron star increases, the London penetration depth decreases, suggesting that quantum gravity aspects may become significant as the neutron star approaches collapse.

Macroscopic quantum aspects are best described by a BCS type theory[5]. However, since BCS needs a quantum theory of the underlying interaction, and since we do not have a microscopic theory of quantum gravity at this moment, a gravitational BCS type theory is not within our reach. Despite this, we can certainly make a plausible argument for what happens at the microscopic scale. Inspired from the Cooper-pair forming electrons in the BCS theory of superconductivity, the Interacting Boson Model (IBM) [6, 7] assumes nucleons to form pairs inside nuclei. These pairs are bosons and by only looking at the interaction of those bosons among themselves, one can explain a wealth of nuclear data to a high degree of accuracy. Neutron stars consist mostly of neutrons and some protons and for low enough temperatures ($< 10^9$K) they are expected to pair up. Experimental evidence for the pairing comes from the theory of cooling of neutron stars, where the reduction of the specific heat due to extensive pairing is essential [8]. In addition, bose-condensation can occur and superfluidity as well as superconductivity are consequences. Evidence for superfluidity can be found in the glitches in the timing history of pulsars [1, 9]. Therefore, although we do not have a microscopic theory of quantum gravity, we have enough evidence justifying a phenomenological investigation of macroscopic quantum gravity effects following London's approach.

Symmetry breaking is a very convenient way to look at macroscopic quantum effects. To break a symmetry one needs a bose-condensate. What causes the bose-condensation and which symmetry is broken are two entirely unrelated problems. Any mechanism leading to an attraction between the fermions at the Fermi surface is equally well suited for producing the bose-condensate. For example, in the standard BCS theory of superconductivity, the attraction is caused by the phonon interaction, the symmetry broken is the electromagnetic U(1) symmetry [10]. In the theory of superfluid helium 3 [11], the attraction is caused by van der Waals forces, the symmetries broken are translational [12] and rotational in spin and orbital space as well as gauge symmetry. In the theory of the Interacting Boson Model, the attraction is caused by the strong nuclear force, the symmetry broken is related to angular momentum and Runge-Lenz vector [6]. In the theory of superconductivity of protons inside neutron stars, the attraction is caused by the strong nuclear force, the symmetry broken is the electromagnetic U(1) symmetry. Therefore, we see no reason why to exclude the scenario, where the attraction is caused by the strong nuclear force and the symmetry broken is gravitational.

This work is also an attempt to probe certain aspects of quantum gravity. The microscopic approach to quantum gravity has been poised with serious problems, and no satisfactory theory has emerged as of yet. The macroscopic approach seems much more tractable, and maybe following the theory of superconductivity from London to Ginzburg and Landau to Bardeen, Cooper and Schrieffer will give us another route to learn more about quantum gravity.

II Gravitational Maxwell Equations

Let us review the post-Newtonian approximation [13, 14]. For weak gravitational fields and low velocities, i.e.,

$$U/c^2 \sim (v/c)^4 \sim \left(p/\rho c^2\right)^2 \sim \left(\Pi/c^2\right)^2 \ll 1,$$

Einstein's field equation can be written in a form resembling Maxwell's equations of electrodynamics. We are mostly interested in magnetic-type gravity, and therefore we shall use the truncated and rewritten version of the parametrized-post-Newtonian (PPN) formalism given by Braginsky et. al. [15]. Scalar and vector potentials are defined as

$$\phi = -(U + 2\Psi) \qquad \text{and} \qquad \mathrm{A_j} = -\frac{7}{2}\mathrm{V_j} - \frac{1}{2}\mathrm{W_j}, \tag{1}$$

where U, Ψ, V_j, and W_j are defined in chapter 39 of Misner, Thorne and Wheeler [14]. This allows us to define a 'gravitoelectric' field $\mathbf{g}$ and a 'gravitomagnetic' field $\mathbf{H}$ through

$$\mathbf{g} = -\nabla\phi - \frac{1}{c}\frac{\partial \mathbf{A}}{\partial t} \qquad \text{and} \qquad \mathbf{H} = \nabla \times \mathbf{A}. \tag{2}$$

In this weak field, slow motion expansion of general relativity, $\mathbf{g}$ contains mostly first order corrections to flat space-time, and $\mathbf{H}$ contains second order corrections. For the solar system, $\mathbf{g}$ is just the normal Newtonian gravitational acceleration, whereas $\mathbf{H}$ is related to angular momentum interactions and effects due to $\mathbf{H}$ are about 10^{12} times smaller than those due to $\mathbf{g}$.

In the above approximation, Einstein's field equations can be rewritten in a form very much resembling that of Maxwell's equations

$$\nabla \cdot \mathbf{g} = -4\pi G\rho_0 + \mathcal{O}\left(c^{-2}\right), \qquad \nabla \times \mathbf{g} = -\frac{1}{\mathrm{c}}\frac{\partial \mathbf{H}}{\partial \mathrm{t}} \tag{3}$$

$$\nabla \cdot \mathbf{H} = 0, \qquad \nabla \times \mathbf{H} = 4\left(-4\pi \mathrm{G}\rho_0\frac{\mathbf{v}}{\mathrm{c}} + \frac{1}{\mathrm{c}}\frac{\partial \mathbf{g}}{\partial \mathrm{t}}\right), \tag{4}$$

where ρ_0 is the density of rest mass in the local rest frame of the matter and $\mathbf{v}$ is the ordinary velocity of the rest mass relative to the PPN coordinate frame. The specific internal energy Π and the pressure p have been neglected since they only contribute $\mathcal{O}\left(c^{-2}\right)$ effects to the electric field.

The equation of motion of an uncharged particle is identical to the electromagnetic Lorentz force law [2, 15],

$$\frac{d\mathbf{v}}{dt} = \mathbf{g} + \frac{1}{c}\mathbf{v} \times \mathbf{H} + \mathcal{O}\left(c^{-2}\right) \tag{5}$$

III Gravitational London Equations

With these gravitational Maxwell equations we can derive the equivalent of London's equations for gravity. The derivation is completely analogous to the electromagnetic case [4, 5, 16, 17]. The Lorentz force law tells us that given a gravitational electric field there will be a resultant acceleration. Multiplying by ρ_0, the matter density, and defining the matter current $\mathbf{j} = \rho_0 \mathbf{v}$, we arrive at

$$\frac{d\mathbf{j}}{dt} = \rho_0 \mathbf{g}. \tag{6}$$

This is sometimes referred to as the first London equation. Now substitute this into the right equation of (3), the equivalent of Faraday's law, we obtain

$$\frac{\partial}{\partial t}\left(\frac{1}{\rho_0}\nabla \times \mathbf{j} + \frac{1}{c}\mathbf{H}\right) = 0. \tag{7}$$

One possible solution to the above equation is obtained by integrating and setting the integration constant to zero. This leads to the second (and most famous) London equation

$$\nabla \times \mathbf{j} = -\frac{\rho_0}{c}\mathbf{H}, \tag{8}$$

which predicts the Meissner-Ochsenfeld effect [18].

In the Ginzburg-Landau theory of superconductivity, it is shown that setting the integration constant in equation (7) to zero is equivalent to the assumption that the significant spatial variation of the order parameter $\psi = |\psi|\, e^{i\phi}$ is through the phase ϕ, and not the magnitude $|\psi|$ [16, 19]. For the density of Cooper pairs this means that it cannot vary appreciably from its uniform thermal equilibrium value. For a superfluid neutron star in thermal equilibrium, where the pairs can flow, but not accumulate or be destroyed, this should be the case.

To obtain the London penetration depth, we take the static part of the right equation of (4)

$$\nabla \times \mathbf{H} = -\frac{16\pi G}{c}\,\mathbf{j} \tag{9}$$

and take the curl of it. Using the second London equation (8) we arrive at

$$\nabla^2 \mathbf{H} = 16\pi \frac{G\rho_0}{c^2}\,\mathbf{H}, \tag{10}$$

where we immediately identify the gravitational London penetration depth

$$\Lambda_L = \left(\frac{c^2}{16\pi G\rho_0}\right)^{1/2} = 5.177 \times 10^{12}\, \rho_0^{-1/2}, \tag{11}$$

where the density ρ_0 is measured in kg/m^3 and Λ_L is given in meters.

IV Coherence Length

For our derivation of the London equations to be valid we must require that the London penetration depth Λ_L is much larger than the coherence length ξ_0 [17]:

$$\Lambda_L \gg \xi_0, \tag{12}$$

where the coherence length is defined through

$$\xi_0 = \frac{\hbar v_F}{\pi \Delta}, \tag{13}$$

with v_F the Fermi velocity and 2Δ the pairing energy or energy gap. We are only interested in a rough estimate of the upper limit of ξ_0. An upper limit for the Fermi velocity obviously is the speed of light. If the pairing is caused by the strong nuclear force, as we assumed, then a lower limit on Δ is a few hundred thousand keV [20]. With these numbers we find for the coherence length

$$\xi_0 \leq 10^{-13}\mathrm{m}, \tag{14}$$

which is larger than the separation between two nucleons, but much smaller than the London penetration depth. Therefore, our derivation of the London equations was justified in the given approximation.

V Discussion

We notice that for regular densities occurring in the universe the gravitational London penetration depth will be a very large number. However, interesting enough, for neutron stars with densities of about $\rho_{NS} \cong 2 \times 10^{17}\mathrm{kg/m}^3$, we obtain a London length of 12km, which is slightly smaller than the radius of a neutron star with that density. The London length is inversely proportional to the density, meaning with increasing density the London penetration depth decreases.

For neutron stars this means that the onset of a gravitational Meissner effect is predicted. In essence it implies that the gravitational magnetic field caused by the huge angular momentum of the neutron star, will be expelled from the center of the neutron star. This could be accomplished through induced matter-supercurrents in the outer layers of the neutron stars, creating counter-magnetic fields to expel the gravitational magnetic field from its interior, in analogy to the electromagnetic case.

A more detailed description is not possible in the approximation used, since the post-Newtonian approximation is only a rough approximation if used for neutron stars. We are currently working on the second order post-Newtonian approximation and numerical simulations [21].

VI Conclusion

More significant than the expulsion of the gravitational magnetic field, however, may be the fact that the Meissner effect is a macroscopic quantum effect, and in essence, the *gravitational* Meissner effect is a macroscopic quantum *gravity* effect. There is experimental evidence that neutron stars are superfluid as well as superconducting. This indicates that macroscopic quantum effects do play a significant role for neutron stars. Furthermore, neutron stars are the strongest gravitational objects observed with certainty. Under the assumptions used here, we find that macroscopic quantum gravity effects may play a significant role for neutron stars.

Since the work of Oppenheimer and Volkoff [22], we know that neutron stars will be stable only up to a certain point. After that the gravitational pressure overcomes the pressure of the neutron Fermi gas and continued collapse is predicted. This leads to increasing densities, and in our model to decreasing London penetration lengths, indicating that gravitational quantum effects might become more and more important. Therefore, we would like to emphasize that the prediction of Oppenheimer and Volkoff is classical in nature, and our work indicates, that a quantum gravitational treatment may lead to new results.

VII Acknowledgment

I would like to thank Professor V.G.J. Rodgers for spawning my interest in this topic and for his insightful guidance throughout this work.

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Updating the Theoretical Analysis of the Weak Gravitational Shielding Experiment.

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Abstract

The most recent data about the weak gravitational shielding produced recently through a levitating and rotating HTC superconducting disk show a very weak dependence of the shielding value ($\sim 1\%$) on the height above the disk. We show that whilst this behaviour is incompatible with an intuitive vectorial picture of the shielding, it is consistently explained by our theoretical model. The expulsive force observed at the border of the shielded zone is due to energy conservation.

74.72.-h High-T_c cuprates.

04.60.-m Quantum gravity.

The measurements of Podkletnov et al. of a possible weak gravitational shielding effect [1, 2] have been repeated several times and under different conditions by that group, with good

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reproducibility, including results in the vacuum. In the forthcoming months other groups will hopefully be able to confirm the effect independently. While the Tampere group was mainly concerned with obtaining larger values for the shielding, studying its dependence on numerous experimental parameters and testing new materials for the disk, in the future measurements it will be important to obtain more exact data, including detailed spatial field maps. The theoretical model suggested by us [3] is still evolving, although at a fundamental level; a more detailed account appears elsewhere [4].

Let us recall in short the main features of the experiment. A HTC superconducting disk or toroid with diameter between 15 and 30 cm, made of $YBa_2Cu_3O_{7-x}$, is refrigerated by liquid helium in a stainless steel cryostat at a temperature below 70 K. The microscopic structure of the material, which plays an important role in determining the levitation properties and the amount of the effect, is described in details in the cited works.

The disk levitates above an electromagnet and rotates by the action of lateral alternating e.m. fields. Samples of different weight and composition are placed over the disk, at a distance which can vary from a few cm to 1 m or more (see below). A weight reduction of about 0.05% is observed when the disk is levitating but not rotating; the weight loss reaches values about 0.5% when the disk rotates at a frequency of ca. 5000 rpm. If at this point the rotating fields are switched off, the sample weight remains decreased till the rotation frequency of the disk decreases. On the other hand, if the rotation frequency is decreased from 5000 to 3500 rpm using the solenoids as breaking tools, the shielding effect reaches maximum values from 1.9 to 2.1%, depending on the position of the sample with respect to the outer edge of the disk.

This effect, if confirmed, would represent a very new and spectacular phenomenon in gravity; namely, as well known, there has never been observed any conventional gravitational shielding up till now, up to an accuracy of one part in 10^{10}, and General Relativity and perturbative Quantum Gravity exclude any measurable shielding [3]. Our temptative theoretical explanation is based on some properties of non-perturbative quantum gravity. We have shown that the density field $|\phi_0|^2$ of the Cooper pairs inside the superconductor or, more likely, the squared gradient $(\partial_\mu \phi_0)^*(\partial^\mu \phi_0)$ may act as localized positive contributions to the small negative effective gravitational cosmological constant Λ; if the sum turns out to be positive in a certain four-dimensional region, a local gravitational singularity arises there, affecting the gravitational propagators and thus the interaction potential (between the Earth and the samples, in this case).

To sketch our model – although not rigorously – we could say that there is an "anomalous coupling" between the mentioned density $|\phi_0|^2$ or the squared gradient $(\partial_\mu\phi_0)^*(\partial^\mu\phi_0)$ and the gravitational field, and that the net result is to partly "absorb" the field. We expect that only in some regions of the superconductor the density $|\phi_0|^2$ or the squared gradient will be strong enough and that the inhomogeneities of the material and the pinning centers will be crucial in determining such regions. Since the gravitational field is attractive, its "absorption" requires energy from the outside. This means that there must be some mechanism external to the disk which *forces* $|\phi_0|^2$ or $(\partial_\mu\phi_0)^*(\partial^\mu\phi_0)$ to take high values. This is caused in the experiment by the action of the external electromagnetic field and by the disk rotation.

The dependence of the shielding effect on the height, at which the samples are placed above the superconducting disk, has been recently measured up to a height of ca. 3 m [5]. No difference in the shielding value has been noted, with a precision of one part in 10^3. It is also remarkable that during the measurement at 3 m height the sample was placed in the room which lies above the main laboratory, on the next floor; in this way the effect of air flows on the measurements was greatly reduced. For the used 500 g sample the weight loss was ca. 2.5 g.

Such an extremely weak height dependence of the shielding is in sharp contrast with the intuitive picture, according to which the gravitational field of the Earth is the vectorial sum of the fields produced by each single "portion" of Earth. In the absence of any shielding, the sum results in a field which is equivalent to the field of a pointlike mass placed in the center of the Earth; this can be checked elementarily by direct integration or invoking Gauss' theorem and the spherical symmetry. But if we admit that the superconducting disk produces a weak shielding, the part of the Earth which is shielded lies behind the projection of the disk as seen from the sample, i.e., within an angle θ about the vertical direction, such that $\tan\theta = h$, where h is the sample height over the disk measured in units of the disk radius. (For simplicity we suppose now the sample to be centered above the disk.)

In order to obtain the shielding effect as a function of h, taking into account this geometrical factor, one must integrate the Newtonian contribution $\cos\phi/R^2$ over the intersection between the Earth and the cone defined by $\phi < \theta$. We have done this for the values $h = 1, 2, 3, 4, 6, 8, 10$, through a Montecarlo algorithm. We took into account the higher density of the Earth's core ($\rho_{core} \sim 2\rho_{mantle}$; $r_{core} \sim (1/2)r_{Earth}$; it is straightforward to insert more accurate values, but the final results change very little); we also computed analytically the contribution of the tip of the cone, from the Earth's surface to the Earth's core, in order to reduce the fluctuations in the Montecarlo samplings for small R. [2] The resulting values were the following:

```
h     shielding/maximum-shielding
=================================
1            0.62  +/- 0.02
2            0.34  +/- 0.01
3            0.18  +/- 0.01
4            0.102 +/- 0.003
6            0.050 +/- 0.002
8            0.029 +/- 0.001
10           0.018 +/- 0.001
```

This strong height dependence is clearly incompatible with the mentioned experimental data, which instead seem to indicate that in the shielding process all the mass of the Earth behaves effectively as if it would be concentrated in one point.

In our theoretical model this property arises in a natural way. We employ a quantum formula which expresses the static gravitational interaction energy of two masses m_1 and m_2 in terms of an invariant vacuum expectation value, namely [6]

$$E = \lim_{T\to\infty} -\frac{\hbar}{T} \log \frac{\int d[g]\, \exp\left\{-\hbar^{-1}\left[S[g] + \sum_{i=1,2} m_i \int_{-\frac{T}{2}}^{\frac{T}{2}} dt\, \sqrt{g_{\mu\nu}[x_i(t)]\dot{x}_i^\mu(t)\dot{x}_i^\nu(t)}\right]\right\}}{\int d[g]\, \exp\left\{-\hbar^{-1} S[g]\right\}} \tag{1}$$

$$\equiv \lim_{T\to\infty} -\frac{\hbar}{T} \log \left\langle \exp\left\{-\hbar^{-1} \sum_{i=1,2} m_i \int_{-\frac{T}{2}}^{\frac{T}{2}} ds_i\right\}\right\rangle_S \tag{2}$$

where g has Euclidean signature and S is the gravitational action of general form

$$S[g] = \int d^4x\, \sqrt{g}\left(\lambda - kR + \frac{1}{4} a R_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma}\right). \tag{3}$$

[2] For the detailed algorithm and figures please ask the author at the e-mail address above.

The constants k and λ are related – in general as "bare quantities" – to the Newton constant G and to the cosmological constant Λ: k corresponds to $1/8\pi G$ and λ to $\Lambda/8\pi G$. The trajectories $x_i(t)$ of m_1 and m_2 are parallel with respect to the metric g; let R be their distance.

In the weak-field approximation, eq. (1) reproduces to lowest order the Newton potential and can be used to find its higher order quantum corrections [7], or implemented on a Regge lattice to investigate the non-perturbative behaviour of the potential at small distances [9]. The addition to the gravitational action (3) of a term which represents a localized *external* Bose condensate [3] mimics a shielding effect which is absent from the classical theory and which we take as our candidate model for the observed shielding.

The feature of eq. (1) which is of interest here is that if the two masses m_1 and m_2 are not pointlike, the trajectories $x_1(t)$ and $x_2(t)$ must be those of their centers of mass. (This also makes irrelevant the question – actually ill-defined in general relativity – whether they are pointlike or not.) Thus, when applying eq. (1) to the Earth and the sample, we only need to consider the centers of mass of those bodies. In this way we reproduce the observed behaviour for the shielding as well as for the regular interaction. The ensuing apparent failure in the "local transmission" of the gravitational interaction does not contrast with any known property of gravity (compare [6, 8], and references about the problem of the local energy density in General Relativity and [6] about the non-localization of virtual gravitons. One should also keep in mind that (1) holds only in the static case.)

Finally, if we describe the shielding effect as a slight diminution of the effective value of the gravitational acceleration g, and remember that the gravitational potential energy $U = -\frac{Gm_{Earth}}{r_{Earth}} = -gr_{Earth}$ is negative, it follows that the energy of a sample inside the shielded zone is larger than its energy outside. This means in turn that the sample must feel an expulsive force at the border of the shielded region. Such a force has been indeed observed [5], although precise data are not available yet. From the theoretical point of view it is however not trivial to do any prevision about the intensity of the force. In fact, the shielding process absorbs energy from the experimental apparatus and thus any transient stage is expected to be highly non-linear, especially for heavy samples.

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Role of a "Local" Cosmological Constant in Euclidean Quantum Gravity.

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Abstract

In 4D non-perturbative Regge calculus a positive value of the effective cosmological constant characterizes the collapsed phase of the system. If a local term of the form $S' = \sum_{h \epsilon \{h_1, h_2, ...\}} \lambda_h V_h$ is added to the gravitational action, where $\{h_1, h_2, ...\}$ is a subset of the hinges and $\{\lambda_h\}$ are positive constants, one expects that the volumes V_{h_1}, V_{h_2}, ... tend to collapse and that the excitations of the lattice propagating through the hinges $\{h_1, h_2, ...\}$ are damped. We study the continuum analogue of this effect. The additional term S' may represent the coupling of the gravitational field to an external Bose condensate.

04.20.-q Classical general relativity.

04.60.-m Quantum gravity.

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Since the first perturbative formulations of quantum gravity it was realized that the addition of a cosmological term $\frac{\Lambda}{8\pi G}\int d^4x\,\sqrt{g(x)}$ to the pure Einstein action gives the graviton a mass, which is positive if $\Lambda < 0$ and negative – that means, the theory becomes unstable – if $\Lambda > 0$ [1].

Nevertheless, whilst the vacuum fluctuations of the quantum fields should in principle produce a very large value of the cosmological constant, there is no observable hint of it. Namely, neither the Newtonian potential shows any finite range up to solar system distances, nor pure gravity exhibits any instability in the weak field case; finally the observations on cosmological scale set an upper limit on $|\Lambda|$ as small as $|\Lambda| < 10^{-120}G^{-1}$ in natural units. This discrepancy is known as the "cosmological constant problem" and several possible escapes have been suggested [2]. Treating the problem at a fundamental level requires a non-perturbative approach, since one should be able to explain why the actual large-scale geometry of spacetime is flat just from dynamic considerations. It is therefore not surprising that a definitive and generally accepted solution of the paradox of the cosmological constant is still remote. We shall not make any attempt to a new explanation here.

We shall consider 4D pure gravity in the Euclidean approach, with special reference to quantum Regge calculus [3]. In this model the results of the numerical non-perturbative simulations compose the following picture of the behaviour of the cosmological constant: while its "bare" value λ is generally nonzero, the effective value Λ depends on the energy scale μ and vanishes at large distances like $|\Lambda| \sim G^{-1}(\mu l_0)^\gamma$, where l_0 is the lattice spacing and γ a critical exponent. This means that the quantum geometry fluctuates on small scales, but reproduces flat space at macroscopic distances. The sign of Λ is negative, thus the flat limit is well defined.

Our aim is to study the interaction of this gravitational system with a particular external source, namely a Bose condensate described by a scalar field $\phi(x) = \phi_0(x) + \tilde{\phi}(x)$. We assume that the vacuum density $\phi_0(x)$ is forced from the outside to a certain value, as it can happen for instance in a superconductor subjected to external electromagnetic fields. The positivity of the Euclidean action of ϕ ensures that the terms $[\partial^\mu\phi_0(x)]^*[\partial_\mu\phi_0(x)]$ and $m_\phi^2|\phi_0(x)|^2$ act like positive cosmological contributions to the gravitational action, possibly inducing local gravitational instabilities.

The structure of the paper is the following. In Section 1 we recall the main results of Euclidean 4D quantum Regge calculus concerning the effective cosmological constant. We mention its scale behaviour and two possible interpretations of the lattice spacing l_0. In Section 2 we consider in the continuum theory, at distances much larger than Planck scale, a weak Euclidean gravitational field $g_{\mu\nu}(x) = \delta_{\mu\nu} + \kappa h_{\mu\nu}(x)$, whose action includes an infinitesimal effective cosmological term with $\Lambda < 0$. Such a theory can be regarded as the continuum limit of the lattice theory described in Section 1. We then couple minimally $g_{\mu\nu}(x)$ to the mentioned scalar field $\phi(x)$, with vacuum density $\phi_0(x)$ determined from the outside, and write in detail the various terms of the action. It turns out that the infinitesimal graviton mass $m_g^2 \propto |\Lambda|$ receives a local negative contribution, which we denote by $-\mu^2(x)$. This means, as we show explicitly for the simpler case of an almost-massless scalar field χ, that if there exist some four-dimensional regions in which $\mu^2(x) > m_\chi^2$, it is possible to find field configurations $\chi(x)$ which make the Euclidean action unbounded from below. The field tends to develope singularities in those regions, or – if a cut-off mechanism comes into play – it tends to assume constant extremal values which are independent from those in the neighboring regions. We suggest that these "constraints" should be inserted in the equation for the propagator of the field.

In Section 3 we remind the formula which gives the static potential energy in Euclidean quantum gravity as a functional average [4, 5]. We illustrate its statistical meaning in the case of a weak field through an analogy with a simple 2D Ising model, which we also treat numerically with an elementary simulation. We show numerically that the insertion of local supplementary constraints due to an external field (in analogy to the singularities of the continuum case) damps in a sensible way the spin-spin correlations, and thus the interaction they represent in the model.

1 Regge calculus.

In the last years discretized quantum gravity on the Regge lattice has led, through the Montecarlo numerical simulations of Hamber and Williams, to a better comprehension of the non-perturbative behaviour of the Euclidean gravitational field in four dimensions. Some of the features which emerge from their results [3] depend on the specific model, but several others are quite general. In this approach the physical quantities are extracted from functional averages. The partition function is written as

$$Z = \int_{Geometries} d[g] \, e^{-\hbar^{-1} S[g]} \tag{1}$$

where the geometries are described by piecewise flat simplicial manifolds. The integral (i.e. the Montecarlo sampling) runs over the lengths of the links which define a field configuration. The action in (1) has the form

$$S = \int d^4x \, \sqrt{g} \left(\lambda - kR + \frac{1}{4} a R_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma} \right) \tag{2}$$

or, in discretized version,

$$S[l] = \sum_{hinges \ h} V_h \left[\lambda - k \frac{A_h \delta_h}{V_h} + a \frac{A_h^2 \delta_h^2}{V_h^2} \right] \tag{3}$$

where A_h is the area of an hinge, V_h its volume and δ_h the defect angle (see the original papers for the definitions of lattice quantities and the functional measure).

In the following we shall set $\hbar = 1$. The constants k and λ are related, as "bare" quantities, to the Newton constant G and to the cosmological constant Λ: k corresponds to $1/8\pi G$ and λ to $\Lambda/8\pi G$. It is important, however, to keep distinct the physical values G and Λ from k and λ. The latter are entered as parameters at the beginning, and then a second order transition point for the statistical system described by Z is found by Montecarlo simulation. Actually, there is a line of transition, since one can also vary the adimensional parameter a, which does not have a macroscopic counterpart. On this line in the parameter space the theory admits a continuum limit. Unlike in perturbation theory, where a flat background is introduced by hand, here the flat space appears dynamically; namely, the average value of the curvature is found to vanish on the transition line, which separates a "smooth phase", with small negative curvature, from a "rough", unphysical phase, with large positive curvature. In this way the effective, large scale cosmological constant

$$\Lambda = \frac{\left\langle \int \sqrt{g} \, R \right\rangle}{\left\langle \int \sqrt{g} \right\rangle} \tag{4}$$

vanishes in the continuum quantum theory.

More precisely, the dependence of the effective (or "running") cosmological constant Λ_{eff} on the scale is the following. If we compute (4) on small volumes, the curvature fluctuates wildly. At larger distances the average curvature decreases, because the fluctuations tend to average out. If μ denotes the energy scale, close to the critical point the adimensional quantity $|\Lambda|G$ behaves like

$$(|\Lambda|G)(\mu) \sim (l_0\mu)^\gamma, \tag{5}$$

where l_0 is the average spacing of the dynamical lattice and $\gamma \sim 1.56$ in the first simulations. The sign of Λ is negative, as mentioned. Since the μ-dependence of G is quite weak, the effective cosmological constant decreases approximately like a power law as the length scale grows.

Eq. (5) admits two different physical interpretations, depending on the role we attribute to the average lattice spacing $l_0 = \sqrt{\langle l^2 \rangle}$. In the usual lattice theories, l_0 is sent to zero in order to obtain the continuum limit. In this first interpretation, eq. (5) shows the way the lattice theory reproduces flat space in the physical limit. No real physical meaning is assigned to the effective Λ which, at a fixed scale μ, is simply proportional to a positive power of the regulator.

On the other hand, we can believe that in quantum gravity l_0 has an intrinsic minimum value of the order of Planck length $L_{Planck} \sim 10^{-33}\ cm$. This hypotesis arises independently from several operational models (for a review see [6]) or from more complex quantum theories (see for instance [7] and references). In the framework of Regge calculus, it is possible to fix l_0 by imposing that the effective Newton constant G computed non-perturbatively [5] is of the same magnitude order of the observed value; in this way one finds one more time that l_0 has to be of the order of Planck length [8].

In this second case, that is $l_0 \sim L_{Planck}$, the interpretation of eq. (5) is different: it means that the effective cosmological constant tends to zero on large scale, while it is nonvanishing, in principle, on small scale (here and in the following we mean by "large" scale the laboratory or atomic scale, and by "small" scale the Planck scale). This interpretation does not necessarily have observable physical consequences, since in fact Λ could be far too small. Namely, the exponent gamma has been computed only for small lattices; an evaluation for lattices of "macroscopic" size is of course technically impossible, and thus only the experiments could tell us whether the law (5) keeps true for large distances, and with which exponent. The fact that on astronomical scale we have $|\Lambda|G < 10^{-120}$ for $\mu \sim 10^{-30} cm^{-1}$ constrains γ to be approximately larger than 2. But the vanishing could be much more rapid, so that we could disregard Λ at any physically relevant scale.

Another property of Regge calculus which shows an intrinsic feature of quantum gravity is the instability of the "rough" phase with positive average curvature, i.e. with positive effective cosmological constant. This phase does not admit any continuum limit. Its fractal dimension is small, which denotes that the geometry is collapsed.

The non-perturbative instability properties of the phase with positive average curvature extend the validity of known considerations based on perturbation theory. Namely, in the weak field approximation a positive cosmological constant in the gravitational lagrangian produces a negative mass for the graviton (compare [1] and the next Section). Instabilities arise in the perturbative theory on a De Sitter background too [9, 10]. On the contrary, a small negative cosmological constant generally does not imply any instability, but a small mass m_g for the graviton, of the order of $\Lambda^{1/2}$ in natural units.

In conclusion, at a scale large enough with respect to the lattice scale it is possible to regard the discretized gravitational functional integral (1) as describing an almost flat mean field plus fluctuations. If the fixed point of the lattice theory is approached from the physical, smooth phase, the effective cosmological constant Λ (i.e. the average of the scalar curvature R) is very small and negative, and the large scale fluctuations of R are small too. The system is stable, because the field configurations with larger volume, in which the links are as stretched as possible, are preferred to the collapsed configurations, since the Euclidean action depends on the volume like $S \sim \frac{\Lambda}{8\pi G} \int d^4x \sqrt{g} \sim \frac{\Lambda}{8\pi G} \sum_h V_h$. (On the contrary, a positive value of Λ would favour the collapsed configurations with smaller volume.) In this picture Λ can be regarded either as a purely formal regulator, which goes to zero in the physical limit $l_0 \to 0$, or as a physical quantity, though possibly extremely small (in the second interpretation, in which $l_0 \sim l_{Planck}$).

Keeping these properties in mind, it is interesting to consider the case in which the coupling of the Euclidean gravitational field with an external source gives in some four-dimensional regions a positive contribution to the effective cosmological constant. In the next Section we shall analyse this phenomenon in the continuum case, that is, on large scale (in the meaning of "large scale" we precised above).

On the lattice, such a coupling would correspond in the action (3) to an additional term of the form

$$\sum_{\{h_1,h_2...\}} \lambda_h V_h \tag{6}$$

where $\{h_1, h_2...\}$ is a subset of the hinges and λ_h are fixed positive constants.

We expect that when the Montecarlo algorithm chooses for the random variation a link which ends in a hinge $h_i \epsilon \{h_1, h_2 ...\}$, the favoured variation will be that for which the volume V_{h_i} decreases. Thus the volumes $\{V_{h_1},\ V_{h_2}, ...\}$ will tend to collapse and the lattice excitations propagating through the hinges $\{h_1, h_2 ...\}$ will be damped.

2 Continuum case.

We have seen that the results of quantum Regge calculus can be interpreted as leading at distances large compared to L_{Planck} to an effective Euclidean action for pure gravity of the form

$$S_{eff} = \int d^4x \sqrt{g(x)} \left[\frac{\Lambda}{8\pi G} - \frac{1}{8\pi G} R(x) \right] \tag{7}$$

where the curvature fluctuations around flat space are small and the effective cosmological constant Λ is negative and very small too. (As we saw in the previous Section, Λ is scale-dependent; we suppose here to stay at some fixed scale.) From the geometrical point of view, the small negative value of Λ stabilizes the system, preventing it from falling into small-volume, collapsed configurations.

In the naive perturbation theory around the flat background the Λ-term represents a small mass for the graviton [2]. Namely, setting $g_{\mu\nu}(x) = \delta_{\mu\nu} + \kappa \tilde{h}_{\mu\nu}(x)$, with $\kappa = \sqrt{8\pi G}$, the determinant g of $g_{\mu\nu}$ can be expanded as

$$g = 1 + \kappa \tilde{h}^{(1)} + \kappa^2 \tilde{h}^{(2)} + ... \ , \tag{8}$$

where $\tilde{h}^{(1)}$, $\tilde{h}^{(2)}$, ... denote expressions which are linear, quadratic etc. in $\tilde{h}_{\mu\nu}$. The linear "tadpole" term $\tilde{h}^{(1)}$ is usually disregarded, since it is proportional to the trace $\tilde{h}^{\mu}_{\mu}$, which vanishes on physical states. The term $\tilde{h}^{(2)}$ takes the form of a graviton mass term, such that the mass is positive when $\Lambda < 0$ (compare [1]). We thus have

$$\begin{aligned} S_{eff} = \textstyle\int d^4x \Big\{ & \left[m_g^2 \tilde{h}^{(2)}(x) - \tilde{R}^{(2)}(x) \right] + \Lambda \left[\kappa \tilde{h}^{(3)}(x) + \kappa^2 \tilde{h}^{(4)}(x) + ... \right] + \\ & - \left[\kappa \tilde{R}^{(3)}(x) + \kappa^2 \tilde{R}^{(4)}(x) + ... \right] \Big\}, \end{aligned} \tag{9}$$

[2] As remarked in [1], this widespread belief is not rigorously true. It has also been proved [11] that all theories of a massive tensor field in Minkowski space which satisfy the usual QFT postulates are incompatible with General Relativity in the limit of vanishing mass. In our reasoning it is not essential to regard the cosmological term as a graviton mass term, but for simplicity we stick to this terminology.

where m_g is proportional to $\Lambda^{1/2}$ and $\tilde{R}^{(2)}$, $\tilde{R}^{(3)}$ ... denote the parts of R which are quadratic, cubic etc. in $\tilde{h}_{\mu\nu}$.

The first bracket contains the quadratic part of the action. The third bracket contains the familiar self-interaction vertices of the graviton, involving respectively 1, 2, ... derivatives of $h_{\mu\nu}$. The second bracket contains self-interaction vertices which are peculiar of the theory with $\Lambda \neq 0$ and do not involve derivatives. We are however not interested in the self-interaction vertices of $h_{\mu\nu}$ in the following.

Now we would like to consider the interaction of $\tilde{h}$ with a scalar field ϕ having non-vanishing vacuum expectation value ϕ_0. We suppose ϕ_0 to be spacetime dependent and denote $\phi(x) = \phi_0(x) + \tilde{\phi}(x)$; $\phi_0(x)$ is regarded as a quantity determined from the outside, that is, as a source term. In this way, the field $\phi(x)$ describes a Bose condensate with ground state density $\phi_0(x)$ fixed by external conditions (like, for instance, the Cooper pairs density in certain superconductors under external e.m. field).

The total action is

$$S = S_{eff} + \int d^4x \sqrt{g(x)} \quad \left\{ \partial_\mu \left[\phi_0(x) + \tilde{\phi}(x) \right]^* \partial_\nu \left[\phi_0(x) + \tilde{\phi}(x) \right] g^{\mu\nu}(x) + \frac{1}{2} m_\phi^2 |\phi_0(x)|^2 \right.$$
$$\left. + \frac{1}{2} m_\phi^2 \left[\phi_0^*(x) \tilde{\phi}(x) + \phi_0(x) \tilde{\phi}^*(x) \right] + \frac{1}{2} m^2 |\tilde{\phi}(x)|^2 \right\} \tag{10}$$

We can rewrite it as

$$S = \int d^4x \sqrt{g(x)} \left\{ \left[\frac{\Lambda}{8\pi G} + \frac{1}{2} \mu^2(x) \right] - \frac{1}{8\pi G} R(x) \right\} + S_1 + S_2, \tag{11}$$

where

$$\frac{1}{2} \mu^2(x) = \frac{1}{2} [\partial_\mu \phi_0^*(x)][\partial^\mu \phi_0(x)] + \frac{1}{2} m_\phi^2 |\phi_0(x)|^2; \tag{12}$$

$$S_1 = \frac{1}{2} \int d^4x \sqrt{g(x)}\, \partial_\mu \phi_0^*(x) \partial_\nu \phi_0(x) \kappa \tilde{h}^{\mu\nu}(x); \tag{13}$$

$$S_2 = \frac{1}{2} \int d^4x \sqrt{g(x)} \Big\{ m_\phi^2 |\tilde{\phi}(x)|^2 + m_\phi^2 \left[\phi_0^*(x) \tilde{\phi}(x) + \phi_0(x) \tilde{\phi}^*(x) \right] +$$
$$+ \left[\partial_\mu \tilde{\phi}^*(x) \partial_\nu \tilde{\phi}(x) + \partial_\mu \phi_0^*(x) \partial_\nu \tilde{\phi}(x) + \partial_\mu \tilde{\phi}^*(x) \partial_\nu \phi_0(x) \right] g^{\mu\nu}(x) \Big\} \tag{14}$$

For brevity, we have not expanded here $\sqrt{g}$ and R like in eq. (9). Let us first look at the terms S_1 and S_2. The term S_1 describes a process in which gravitons are produced by the source $\phi_0(x)$. The term S_2 contains the free action of the field $\tilde{\phi}(x)$, which describes the excitations of the condensate, and several vertices in which the graviton field $\tilde{h}_{\mu\nu}(x)$ and $\tilde{\phi}(x)$

interact between themselves and possibly with the source. All these interactions are not of special interest here and are generally very weak, due to the smallness of the coupling κ. The relevant point is that the purely gravitational cosmological term $\frac{\Lambda}{8\pi G}$ receives a "local" positive contribution $\frac{1}{2}\mu^2(x)$ which depends on the fixed external source $\phi_0(x)$. According to eq.s (9), (7) and to our discussion of the sign of Λ, this amounts to a negative mass contribution and could lead to instabilities.

Let us study the effect of such a local negative mass contribution in the simpler case of a scalar field in flat space. We consider a scalar field χ with very small mass m_χ and add to its free Euclidean action a source term of the form $-\frac{1}{2}\mu^2(x)\chi^2(x)$, which represents a "localized negative mass". The action becomes

$$S_\chi = \frac{1}{2}\int d^4x \left\{[\partial^\mu\chi(x)][\partial_\mu\chi(x)] + m_\chi^2\,\chi^2(x) - \mu^2(x)\chi^2(x)\right\} \tag{15}$$

To fix the ideas, let us suppose that $\mu^2(x)$ is different from zero in certain four-dimensional regions Ω_i, where it takes the constant values μ_i. Outside these regions let $\mu^2(x)$ go rapidly to zero. The solution of the classical field equation for χ is obtained by minimizing the action. In the absence of the source term we would have of course $\chi(x) = const. = 0$, because this minimizes at the same time the gradient term $\frac{1}{2}[\partial^\mu\chi(x)\partial_\mu\chi(x)]$ and the mass term $\frac{1}{2}m_\chi^2\,\chi^2(x)$ (both positive-defined).

In the presence of the source term $-\frac{1}{2}\mu^2(x)\chi^2(x)$, the action decreases when χ^2 becomes large within the regions Ω_i. The growth of χ in these regions is limited only by the fact that outside them χ must go to zero (due to the term m_χ^2) and that the gradient in the transition region cannot in turn be too large. Let us suppose for instance that there is only one region Ω_0, with the shape of a 4-sphere of radius r_0. Let $\mu(x)$ take the value μ_0 inside Ω_0 and zero outside. We consider for χ the trial function $\chi(r) = \chi_0\, f(r)$. The action becomes (we admit spherical symmetry)

$$S_\chi = \pi^2\chi_0^2 \int_0^\infty dr\, r^3 \left\{[f'(r)]^2 + m_\chi^2[f(r)]^2 - \mu_0^2\theta(r-r_0)[f(r)]^2\right\} \tag{16}$$

We see that if the integral is positive, the value of χ_0 which minimizes the action is still $\chi_0 = 0$. On the contrary, if the integral is negative, the action is not bounded from below as χ_0 grows.

We choose the following explicit form of $f(r)$: for $r < r_0$ let $f(r) = 1$, i.e., $\chi(r) = \chi_0$; for

$r > r_0$ let be $f(r) = \exp[-(r - r_0)/\delta]$. We thus have

$$S_\chi = \pi^2 \chi_0^2 \left\{ \left(\frac{1}{\delta^2} + m_\chi^2 \right) \int_{r_0}^{\infty} dr\, r^3\, e^{-2(r-r_0)/\delta} - \frac{1}{4}(\mu_0^2 - m_\chi^2) r_0^4 \right\} \tag{17}$$

$$= \pi^2 \chi_0^2 \left\{ \left(\frac{1}{\delta^2} + m_\chi^2 \right) \left(\frac{3}{8}\delta^4 + \frac{3}{4} r_0 \delta^3 + \frac{3}{4} r_0^2 \delta^2 + \frac{1}{2} r_0^3 \delta \right) - \frac{1}{4}(\mu_0^2 - m_\chi^2) r_0^4 \right\} \tag{18}$$

It is easy to check that for suitable choices of the parameters the expression within the braces in eq. (18) turns out to be negative. For instance, if m_χ can be disregarded with respect to μ_0 and $\delta \sim r_0$, the expression is negative provided $\mu_0 \gg \delta^{-1}$. If $\delta \ll r_0$ the expression is negative provided $\mu_0 \gg r_0^{-1}$, etc. Thus the system is unstable. For the graviton the instability is even worse, because the kinetic term $\tilde{R}^{(2)}$ is not positive-definite.

Physically, we might of course invoke some additional "regularizing" process which comes into play for large values of χ_0 and cuts the action. Thus the value of $\chi^2(x)$ inside the region is forced by the source to a certain maximum, and this will affect the propagation of the field. The differential equation for the propagator of $\chi(x)$ in the presence of the source must now satisfy additional boundary conditions on each region Ω_i. This amounts to a very complex mathematical problem; the physical consequence will be a "damping" of the correlations of $\chi(x)$. One can check this numerically in some model; we shall do this shortly in the next Section, referring to a toy bidimensional spin model.

3 The formula for the static potential energy.

In this Section we remind the formula which gives the static potential energy in Euclidean quantum gravity as a functional average [4, 5]. We illustrate its statistical meaning in the case of a weak field through an analogy with a simple 2D Ising model, which we also treat numerically with an elementary simulation. We show numerically that the insertion of local supplementary constraints due to an external field (in analogy to the singularities of the continuum case) damps in a sensible way the spin-spin correlations, and thus the interaction they represent in the model.

Let us first consider, in Euclidean quantum field theory, a scalar field $\Phi(x)$ with action $S_0[\Phi] = \int d^4x\, L(\Phi(x))$. In the presence of the external source $J(x)$, the ground state energy of the system can be expressed as

$$E = \lim_{T\to\infty} -\frac{\hbar}{T} \log \frac{\int d[\Phi] \exp\left\{-\hbar^{-1}\left[\int d^4x\, L(\Phi(x)) + \int d^4x\, \Phi(x)J(x)\right]\right\}}{\int d[\Phi] \exp\left\{-\hbar^{-1}\int d^4x\, L(\Phi(x))\right\}}$$
$$= \lim_{T\to\infty} -\frac{\hbar}{T} \log \left\langle \exp\left\{-\hbar^{-1}\int d^4x\, \Phi(x)J(x)\right\}\right\rangle, \tag{19}$$

where it is assumed that the source vanishes outside the interval $(-T/2, T/2)$ and that the coupling between J and Φ is linear. More generally, a formula similar to (19) holds when we are dealing with more fields Φ_A and corresponding sources J^A, and when the coupling between fields and sources is not linear.

As an useful application of eq. (19), we can write the interaction energy $E(L)$ of two static pointlike sources of the field, kept at a fixed distance L. We just need to insert the suitable expression for J. The trajectories of the two sources are in flat space

$$x_1^\mu(t_1) = (t_1,\, 0,\, 0,\, 0); \qquad x_2^\mu(t_2) = (t_2,\, L,\, 0,\, 0). \tag{20}$$

In ordinary gauge theories we may re-obtain in this way the Wilson formula for the static quark-antiquark potential. In quantum gravity we are led to the following equation for the static potential [4]

$$E(L) = \lim_{T\to\infty} -\frac{\hbar}{T} \log \frac{\int d[g]\, \exp\left\{-\hbar^{-1}\left[S[g] + \sum_{i=1,2} m_i \int_{-\frac{T}{2}}^{\frac{T}{2}} dt\, \sqrt{g_{\mu\nu}[x_i(t)]\dot{x}_i^\mu(t)\dot{x}_i^\nu(t)}\right]\right\}}{\int d[g]\, \exp\left\{-\hbar^{-1}S[g]\right\}} \tag{21}$$

$$\equiv \lim_{T\to\infty} -\frac{\hbar}{T} \log \left\langle \exp\left\{-\hbar^{-1} \sum_{i=1,2} m_i \int_{-\frac{T}{2}}^{\frac{T}{2}} ds_i\right\}\right\rangle_S \tag{22}$$

where S is the euclidean action [3].

In eq.s (21), (22) the lines $x_1(t)$ and $x_2(t)$ must be parallel with respect to the dynamic metric $g_{\mu\nu}$ and thus they should in principle be re-traced for each field configuration of the functional integral. In practice, it is extremely difficult to compute a functional integral defined in such a formal way. Let us then limit ourselves to consider weak fluctuations of the gravitational field about flat space. The trajectories of the sources may be defined with respect to the background

[3] Notice that this formula applies also to two masses which are not pointlike ("pointlike particle" is actually an ill-defined concept in General Relativity), provided we can disregard the internal degrees of freedom. Namely, their action is still equal to $\sum_i \int ds_i$, where the integrals are taken along the trajectories of the centers of mass.

metric like in (20). It is straightforward to reproduce in this way the Newton potential energy [4, 5]; higher order corrections have been computed too [12]. The geodesic distance between the trajectories $x_1(t)$ and $x_2(t)$ is now equal to L only on the average; in fact such an approximation is not without physical meaning, since in any realistic source the fixed distance at which the two masses are kept can only be an average value. Also in the non-perturbative evaluations of eq. (22) in quantum Regge gravity [5], the distance L is evaluated *a posteriori* as the mean value of the geodesic distance on all configurations.

Let us consider the almost-flat metric $g_{\mu\nu} = \delta_{\mu\nu} + \eta_{\mu\nu}$ in a fixed gauge. We obtain

$$\int_{-T/2}^{T/2} ds_i \simeq \int_{-T/2}^{T/2} dt_i \sqrt{1 + h_{11}[x(t_i)]} \simeq T + \frac{1}{2} \int_{-T/2}^{T/2} dt_i \, h_{11}[x(t_i)] \tag{23}$$

and we see that to a first approximation the fluctuations of h have the effect of making each line "shorter" or "longer". Let us call $\alpha[h]$ the (gauge-invariant) difference between the lenghts of the two lines in a field configuration h, and assume for simplicity that the masses of the two sources are equal: $m_1 = m_2 = m$. We may expand the exponential in eq. (22), finding (note that $\langle \alpha[h] \rangle$ obviously vanishes by symmetry)

$$E = 2m + \lim_{T\to\infty} -\frac{\hbar}{T} \log \left\langle \exp\{-\hbar^{-1} m\alpha[g]\} \right\rangle = 2m + \lim_{T\to\infty} -\frac{m^2}{2\hbar T} \left\langle \alpha^2[g] \right\rangle + ... \tag{24}$$

This equation exibits an interesting relation between the vacuum fluctuations of the geometry and the static gravitational potential. To illustrate better its "statistical" meaning we would like now to introduce a toy analogy with the 2D Ising model.

Let us consider a planar spin system with periodic boundary conditions and the local coupling $H = -J \sum_{i,j} s_{ij} s_{i'j'}$ ($J > 0$; (i', j') neighbours of (i, j)). Let us then consider two columns j_1 and j_2 at a distance of L lattice spacings (see fig. 1).

We can regard this system as the analogue of a discretized configuration of a 4D gravitational field on the plane between the two parallel lines of eq. (20). The spin variables ± 1 represent fluctuations of the metric. At the transition temperature, the fluctuations of the spin variables along the two lines are correlated, approximately like $1/L$.

Going back to eq. (23) and making the correspondence $s \leftrightarrow h_{11}$, we see that the analogue of $\alpha[g]$ is the difference between spin sums taken along the columns j_1 and j_2. The analogue of eq. (24) is

$$\langle \alpha^2_{Ising} \rangle \quad = \quad \left\langle \left(\sum_i s_{ij_1} - \sum_i s_{ij_2} \right)^2 \right\rangle =$$

$$= \left\langle \left(\sum_i s_{ij_1}\right)^2 + \left(\sum_i s_{ij_2}\right)^2 - 2\sum_i s_{ij_1} \sum_k s_{kj_2} \right\rangle \tag{25}$$

We are interested only in the term which depends on the distance L between the two columns, that is, the product term

$$p_{12} = \left\langle \sum_i s_{ij_1} \sum_k s_{kj_2} \right\rangle . \tag{26}$$

```
+ - - + -  +  + - - +  -  - + - + + -

+ + + - -  +  + - + -  +  - - + - + +

- - + + -  +  - + + +  -  - + - + + -

+ - + + -  -  + + + -  +  - + + - + +

- + - - +  -  + + - +  +  + - + - + +

+ + + - -  +  + - + -  +  - - + - + +

- + - - +  +  - + - -  +  + - - + - -

- - + + -  +  - + + +  -  + + - + + -

+ + - + -  +  + - - +  -  - + - + + -

- + - - +  -  + + - +  +  + - + - + +

- - + + -  +  - + + +  -  - + - + + -

           |           |

          j1          j2


            <----L---->
```

Fig. 1 - Spin sums taken along two columns of a 2D Ising system.

A numerical simulation with a simple 10×12 system has given, as expected, the following results at the critical temperature:

L (lattice spacings)	p_{12}
2	1.15 +/- 0.13
3	0.74 +/- 0.09
4	0.48 +/- 0.09
5	0.42 +/- 0.08
6	0.41 +/- 0.08

We see that the L^{-1} law is approximately verified also for the correlation between the spin sums taken along the two columns. Only for $L = 6$ there is a deviation, which can be explained as due to the periodic boundary conditions.

We observe that, due to the nature of the spin system, the correlation between two spin sums along j_1 and j_2 is necessarily positive. Thus, the part of $\langle \alpha^2_{Ising} \rangle$ which depends on the distance L is negative. In perturbative quantum gravity one finds instead that the correlation $\langle h_{11}(x) h_{11}(y) \rangle$ is always negative, which leads to the correct negative sign for the potential energy in eq. (24).

```
0 x 0 0 0 0 x 0 0 0 0 0          0 x 0 0 0 0 x 0 0 0 0 0
0 x 0 0 0 0 x 0 0 0 0 0          0 x 0 * 0 0 x 0 0 0 0 0
0 x 0 * 0 0 x 0 0 0 0 0          0 x 0 0 0 0 x 0 0 0 0 0
0 x 0 0 0 0 x 0 0 0 0 0          0 x 0 0 * 0 x 0 0 0 0 0
0 x 0 0 * 0 x 0 0 0 0 0          0 x 0 0 0 0 x 0 0 0 0 0
0 x 0 0 0 0 x 0 0 0 0 0          0 x 0 0 * 0 x 0 0 0 0 0
0 x 0 * 0 0 x 0 0 0 0 0          0 x 0 0 0 0 x 0 0 0 0 0
0 x 0 0 0 0 x 0 0 0 0 0          0 x 0 * 0 0 x 0 0 0 0 0
  |         |                      |         |
  j1        j2                     j1        j2

           (a)                              (b)
```

Fig. 2 - Insertions of singular points "*" between the columns j1 and j2.

We now introduce some supplementary conditions, in order to simulate the case in which the spin variables assume on certain sites a fixed value. This could be due, like in the gravitational case to which we are interested, to the localized action of an external field. In the spin model we may imagine that an external magnetic field localized on certain sites forces spin-flips. With reference to Fig. 2, let us suppose that the spin-flips occurr on the sites marked with a star and placed between the two columns j_1 and j_2 whose correlation we are measuring. (The two columns are denoted by "x", while all the remaining sites are denoted by "0".) To prevent an uncontrolled ”driving” of the total magnetization, we associate to each spin-flip an opposite flip on a neighboring site. The flips occurr at each Montecarlo step; since the mean frequency at which the regular sites are flipped during the simulation is 120 times smaller, the resulting effect is to force a zero at the ”*” sites.

The precise positions of the sites at which the spin-flips happen are almost irrelevant; we find in all cases, as appears from the following table, a sensible diminution of the correlations between the spin sums taken along the columns j_1 and j_2:

```
  Number of "*" sites           p_{12} for L=5
=================================================
     3 (Fig. 2.a)                 0.19 +/- 0.04
     4 (Fig. 2.b)                 0.13 +/- 0.03
```

It appears therefore that the insertion of variables which are driven by an external field damps the correlations in the system, and that this mechanism is of a quite general nature, although we are not able to give a precise analytical description yet.

4 Conclusive remarks.

We have investigated in this paper an unusual interaction mechanism between gravity and a macroscopic quantum system driven by external fields. This idea was originally suggested by a possible phenomenological application [13, 14], but the mechanism is interesting also from the purely theoretical point of view and deserves further numerical and analytical investigation.

We have shown that under certain conditions the gravitational field becomes unstable and may develope singularities, but we have not tried to find a physical regularization and to compute the effect of the regularized singularities yet. Simple physical analogies show however that they generally reduce the gravitational long-range correlations. Our next task will be the esplicit estimation of the changes in the correlation functions in terms of the squared density $|\phi_0(x)|^2$ of the Bose condensate and of its squared gradient $[\partial_\mu \phi_0(x)]^* [\partial^\mu \phi_0(x)]$.

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LETTER TO THE EDITOR

The ac magnetic response in type-II superconductors

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Abstract. The ac response of type-II superconductors to an alternating magnetic field is numerically studied on the basis of the time-dependent Ginzburg–Landau equations. We examine the temperature dependence of the ac susceptibility associated with a small ac magnetic field in the absence of a bias dc field. It is shown that with increasing temperature the in-phase component of the fundamental susceptibility exhibits a step-like change from a negative constant value to zero, while the out-of-phase component of the fundamental susceptibility and the third-harmonic component have a peak at a certain temperature near the superconducting transition temperature. These results are in qualitative agreement with those of recent experiments on high-T_c superconductors.

Magnetization measurements using alternating fields have been widely employed in the study of type-II superconductors [1]. This is because in these experiments the effective time window can be easily changed by varying the frequency of the applied ac field. Thus, the study of the ac magnetic response of type-II superconductors provides direct information on flux dynamics in these materials. Recently, several authors have measured the ac susceptibility in high-T_c materials as functions of various physical parameters such as temperature, and the frequency and amplitude of the applied ac field [2–5].

Various models have been proposed to explain experimental data for the ac susceptibility of type-II superconductors, and especially of high-T_c materials [6–12]. Although these models have partially succeeded in explaining the ac magnetic response of type-II superconductors, they are at rather macroscopic and/or phenomenological levels, and thus are still incomplete. In this letter, to complement the previous study, we attack the above problem by using a different type of approach, that is, the numerical approach of the time-dependent Ginzburg–Landau (TDGL) equations [13, 14]. The main advantage offered by this computer simulation study is the ability to visualize the dynamical processes of magnetization and thus to directly obtain information on the dynamics of the magnetic flux structure without making any of the *ad hoc* electrodynamical assumptions used in previous models (e.g., the field dependence of the critical current in the critical state model). Here, performing numerical calculation of the TDGL equations, we examine the ac magnetic response of type-II superconductors to a small alternating magnetic field in the absence of the steady bias field. In particular, we discuss the temperature dependence of the ac susceptibility with the amplitude and frequency of the ac field being fixed.

The TDGL equations are composed of two partial differential ones for the complex order parameter $\psi(\boldsymbol{r}, t)$ and the vector potential $\boldsymbol{A}(\boldsymbol{r}, t)$ at time t and position $\boldsymbol{r}$ [13–15]:

$$\frac{\hbar^2}{2mD}\left(\frac{\partial}{\partial t} + \mathrm{i}\frac{e\phi}{\hbar}\right)\psi = -\frac{\delta F}{\delta\psi^*} + f(\boldsymbol{r}, t) \tag{1}$$

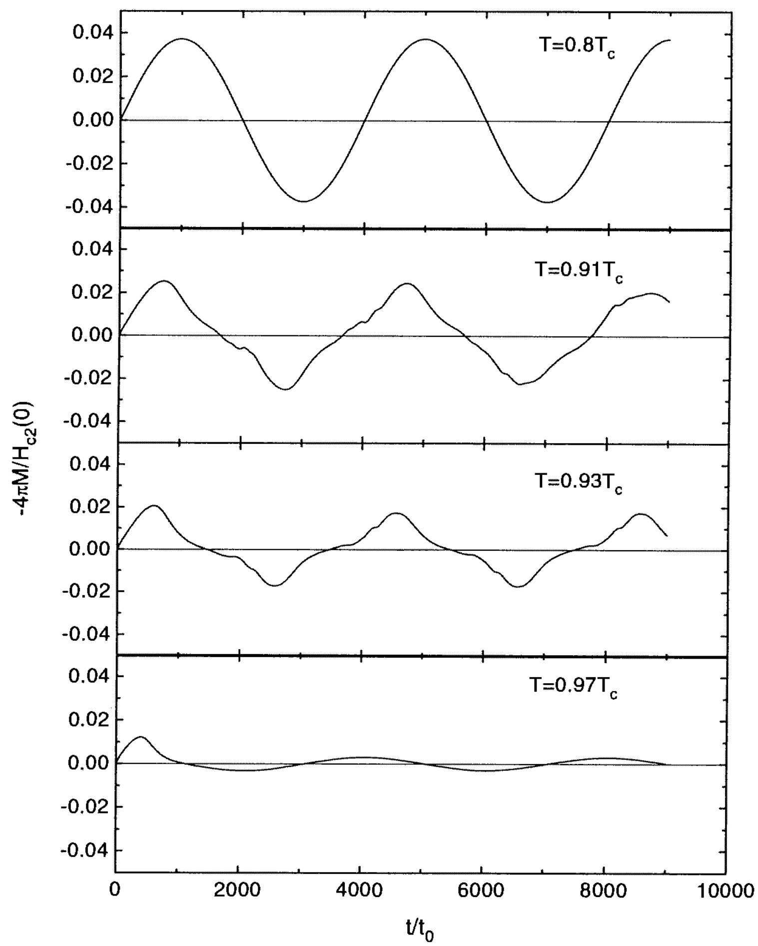

Figure 1. Time variation of the magnetization $M(t)$ for $T/T_c = 0.8$, 0.91, 0.93, and 0.97.

$$\sigma\left(\frac{1}{c}\frac{\partial \boldsymbol{A}}{\partial t} + \boldsymbol{\nabla}\phi\right) = -\frac{\delta F}{\delta \boldsymbol{A}} \tag{2}$$

with the covariant time derivative $(\partial/\partial t + \mathrm{i}e\phi/\hbar)$ and a scalar potential ϕ, where ψ^* denotes the complex conjugate of ψ. These equations are invariant under the local U(1) gauge transformation for ψ, $\boldsymbol{A}$, and ϕ. Here, D and σ are the diffusion constant and the conductivity, associated with the normal phase, respectively, and they have the relation [16]

$$\sigma = \frac{c^2\xi^2}{48\pi\lambda^2}\frac{1}{D} \tag{3}$$

with the coherence length ξ and the magnetic penetration depth λ. The last term of the r.h.s. of equation (1), $f(\boldsymbol{r}, t)$, denotes the thermal noise with zero mean, i.e. $\langle\langle f\rangle\rangle = 0$, and the correlation

$$\langle\langle f^*(\boldsymbol{r}', t')f(\boldsymbol{r}, t)\rangle\rangle = 12\xi_0^{-4}t_0k_BT\left(\frac{H_c(0)^2}{8\pi}\right)^{-1}\delta(\boldsymbol{r}' - \boldsymbol{r})\delta(t' - t) \tag{4}$$

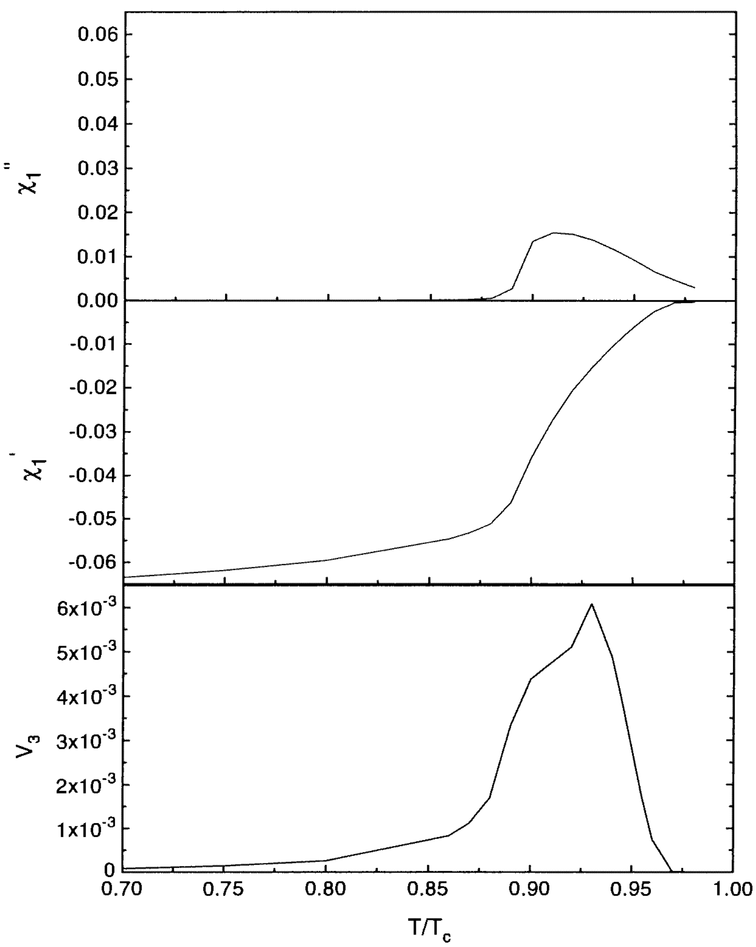

Figure 2. Temperature dependences of χ_1', χ_1'', and V_3.

where $\langle\langle\cdots\rangle\rangle$ denotes the ensemble average, ξ_0 is the coherence length at zero temperature, and $t_0 \equiv \pi\hbar/(96k_BT_c)$ with the superconducting transition temperature T_c at zero field. The Ginzburg–Landau (GL) free-energy functional $F[\psi, \boldsymbol{A}]$ is given by

$$F = \int \mathrm{d}\boldsymbol{r}\ \left[\frac{1}{2m}|\boldsymbol{D}\psi|^2 + \alpha(T)|\psi|^2 + \frac{\beta}{2}|\psi|^4 + \frac{1}{8\pi}(\boldsymbol{\nabla}\times\boldsymbol{A})^2\right] \tag{5}$$

with the covariant derivative $\boldsymbol{D} \equiv -\mathrm{i}\boldsymbol{\nabla} - (e/c)\boldsymbol{A}$ and the local magnetic flux density $\boldsymbol{b}(\boldsymbol{r}, t) \equiv \boldsymbol{\nabla}\times\boldsymbol{A}$. Under the assumption that $\alpha(T) = \alpha(0)(T/T_c - 1)$, and $\alpha(0)$ and β are positive constants in equation (5), the upper and lower critical fields are given by $H_{c2}(T)/H_{c2}(0) = 1 - T/T_c$ and $H_{c1}(T)/H_{c2}(0) = (\ln\kappa/(2\kappa^2))(1 - T/T_c)$, respectively, with the GL parameter κ. The other notation is conventional [16]. These equations are supplemented with boundary conditions, $\boldsymbol{D}\psi|_n = 0$ and $\boldsymbol{\nabla}\times\boldsymbol{A}|_s = \boldsymbol{H}_e$, where the index n denotes the normal direction on the sample boundary and the index s denotes the sample boundary with an applied magnetic field $\boldsymbol{H}_e$.

We here consider a type-II superconductor in the x–y plane with a size $L_x \times L_y$. The

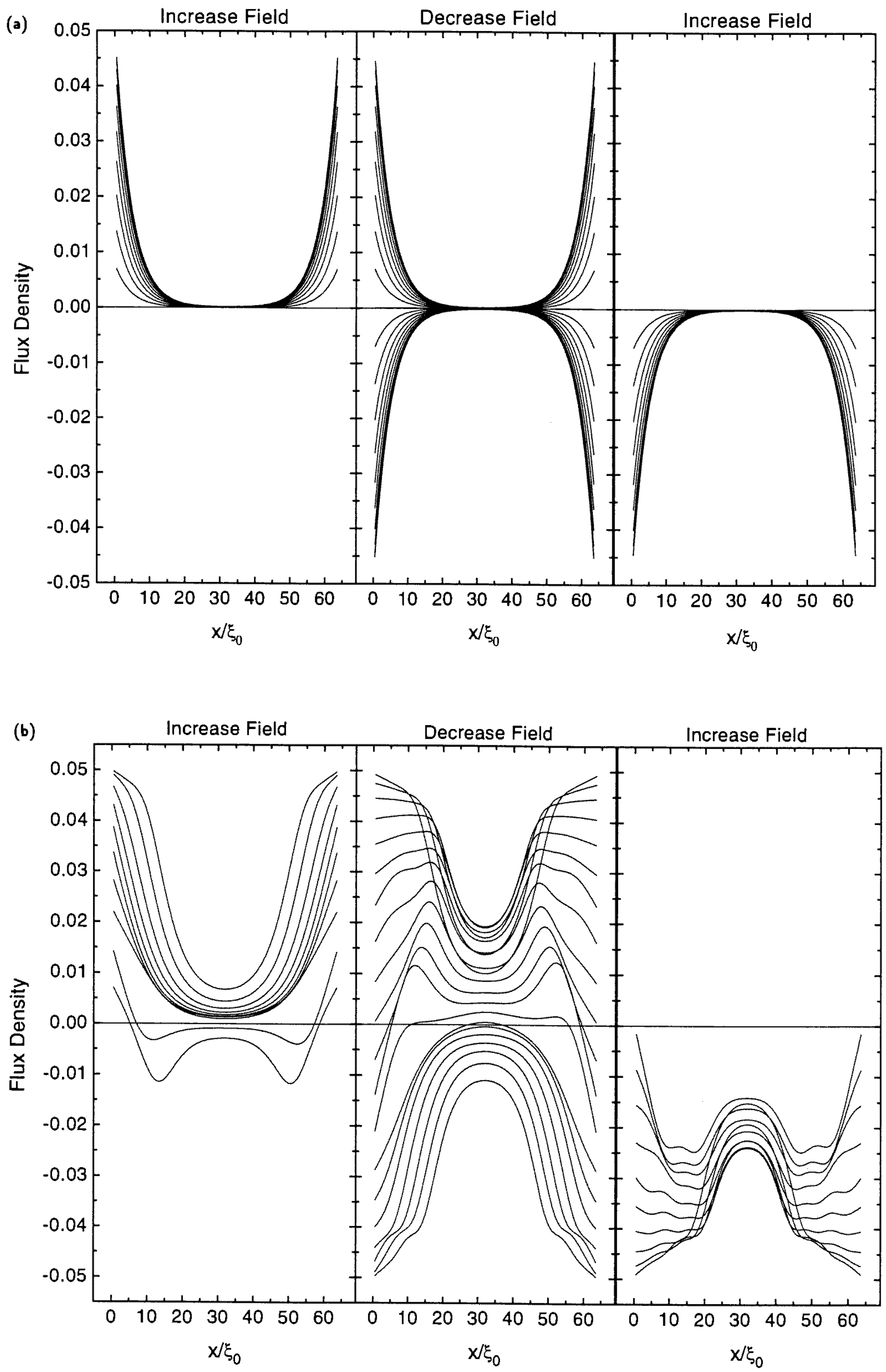

Figure 3. See facing page.

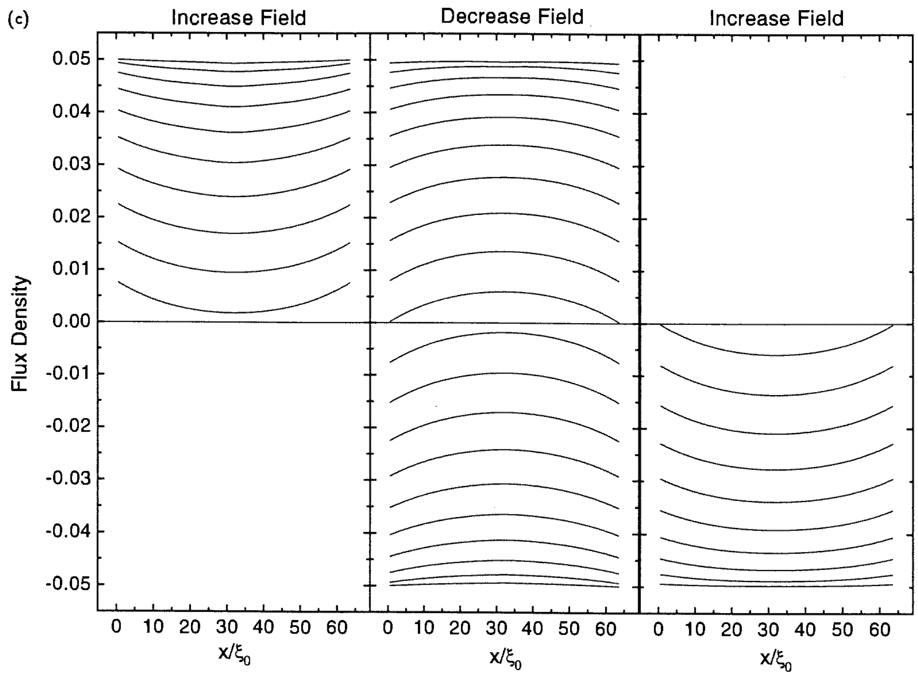

Figure 3. (Continued) Time variations of profiles of the z-component of the local magnetic flux density, b_z, in units of $H_{c2}(0)$ along the x-axis at $y = 32\xi_0$ for $T/T_c = 0.8$ (a), 0.91 (b), and 0.97 (c). Time goes from the left-hand column to the right-hand one for one cycle of the ac field.

sample is assumed to be infinite in the z-direction, and the problem is reduced to two dimensions neglecting all derivatives along z. The external ac magnetic field is applied to the sample as $\boldsymbol{H}_e = H(t)\hat{\boldsymbol{z}}$ with $H(t) = H_{ac}\sin\omega t$ where H_{ac} and ω denote the amplitude and angular frequency of the ac field, respectively, and $\hat{\boldsymbol{z}}$ is the unit vector along the z-axis. In actual simulations the TDGL equations are transformed into the dimensionless discretized equations on a two-dimensional lattice by introducing link variables for the vector potential and the gauge fixing such that the scalar potential is set to zero. Since these procedures are the same as those in references [13, 14], we will not discuss the numerical procedures any further.

In the following simulations, we set $L_x = L_y = 64\xi_0$ and $\kappa = 2$. The amplitude and frequency of the ac field are fixed to be $H_{ac} = 0.05H_{c2}(0)$ and $\omega t_0/2\pi = 0.25 \times 10^{-3}$ (that is, the period of the ac field is $4000t_0$), respectively. We also take the lattice spacing and time step for numerical calculations to be $0.5\xi_0$ and $0.0125t_0$, respectively. These values are chosen for the computational reason of obtaining efficient results within our computer availability. As the initial state we choose the zero-field-cooling state.

In figure 1 the magnetization, $M(t)$, of the sample is plotted against time for various values of temperature. The magnetization $M(t)$ is defined as $4\pi M(t) = \langle B\rangle(t) - H(t)$, where the magnetic induction $\langle B\rangle(t)$ is obtained from the sample average of the z-component, $b_z(\boldsymbol{r}, t)$, of the local magnetic flux density $\boldsymbol{b}(\boldsymbol{r}, t)$. At $T = 0.8T_c$, the magnetization is sinusoidal in nature, according to the external ac field $H_{ac}\sin\omega t$. With increasing temperature, the magnetization deviates from the sinusoidal character with a decrease of its magnitude, and simultaneously a phase-shift phenomenon occurs in the t–$M(t)$ curve. Further increase of temperature results in the large degree of phase shift. Indeed, at $T = 0.97T_c$, the magnetization becomes almost zero at times when the applied ac field is maximum (minimum). Note that even for no bulk pinning case, the phase-shift phenomena take place due to the sample boundary effect, as has been discussed in our previous work [17].

To give details of the ac magnetic response of the system, we study the ac susceptibility defined by the Fourier transformation of the magnetization $M(t)$:

$$M(t) = H_{ac} \sum_{n=1}^{\infty} (\chi_n' \sin n\omega t - \chi_n'' \cos n\omega t) \tag{6}$$

where χ_n' and χ_n'' ($n = 1, 2, \ldots$) denote the in-phase and out-of-phase components of the nth-harmonic susceptibility, respectively, with the nth harmonics $V_n \equiv \sqrt{\chi_n'^2 + \chi_n''^2}$. In calculating the ac susceptibility, simulation data during the first period have been discarded to avoid transient effects. In the present case we have numerically checked that only odd harmonics are generated [8]. In figure 2, χ_1', χ_1'', and V_3 are plotted as functions of temperature; they have been often measured experimentally. It is shown that with increasing temperature, χ_1' exhibits a step-like change from a negative constant value ($=-1/(4\pi)$ theoretically [6]) to zero, while χ_1'' initially rises from zero, goes through a maximum at $0.91T_c$ (called the peak temperature, denoted by T_p), and then returns to a small value near T_c. Note that $H_{c1}(T_p) \simeq 0.008 < H_{ac} = 0.05 < H_{c2}(T_p) = 0.09$ for $T_p = 0.91T_c$ in units of $H_{c2}(0)$. The third harmonic V_3 is also found to have a similar temperature dependence to χ_1'' with the peak temperature $T_p = 0.93T_c$. These results are qualitatively consistent with those of recent experiments on high-T_c superconductors [2–5]. At present it is unclear whether the slight difference between the peak temperature estimated from χ_1'' and that from V_3 is physically meaningful or not.

Now we relate the above macroscopic behaviour of the system to the spatio-temporal structure of the local magnetic flux. In figures 3(a)–3(c) the time evolution of the profile of the local magnetic flux density b_z along the x-axis is shown at $y = 32\xi_0$ for a complete cycle of the ac field for $T/T_c = 0.8$ (a), 0.91 (b), and 0.97 (c), respectively. In figure 4 the time evolution of the profile of the y-component of the current density is shown along the x-axis at $y = 32\xi_0$ for $T = 0.91T_c$ during one half of the period of the ac field, as well as b_z. The current density is given by $(c/4\pi)\boldsymbol{\nabla} \times \boldsymbol{\nabla} \times \boldsymbol{A}$ in units of $j_0 \equiv cH_{c2}(0)/(4\pi\xi_0)$. No definite magnetic vortex structures are observed in figures 3(a)–3(c). It is also found that the step in χ_1' is due to the transition from near-perfect screening (figure 3(a)) to complete penetration ($\langle B\rangle(t) \simeq H(t)$) of the ac field impinging into the whole sample (figure 3(c)). Moreover, we have numerically checked that the smallest temperature at which penetrating magnetic flux (current) reaches to the centre of the sample is $0.90T_c$ in the present case. Thus, the peak in χ_1'' (and maybe the peak in V_3) corresponds to the first penetration of the flux (current) to the centre of the sample (figure 3(b) and figure 4). Although such an interpretation has been already proposed by several authors [7, 9, 10], this is the first simulation study to discuss the ac magnetic response of type-II superconductors from the point of view of the local magnetic flux dynamics without making any of the *ad hoc* electrodynamical assumptions used in previous models. Finally, we remark that the magnetic relaxation phenomenon can be seen in figure 3(b) and figure 4. Indeed, even when the external field changes to a decreasing stage from the initial ramp-up phase, the magnetic flux near the centre of the sample still increases for a while. An importance of this relaxation behaviour has recently been pointed out as one of possible causes for the frequency dependence of the ac susceptibility [3, 12]. Such magnetic relaxation effects on the ac susceptibility will be

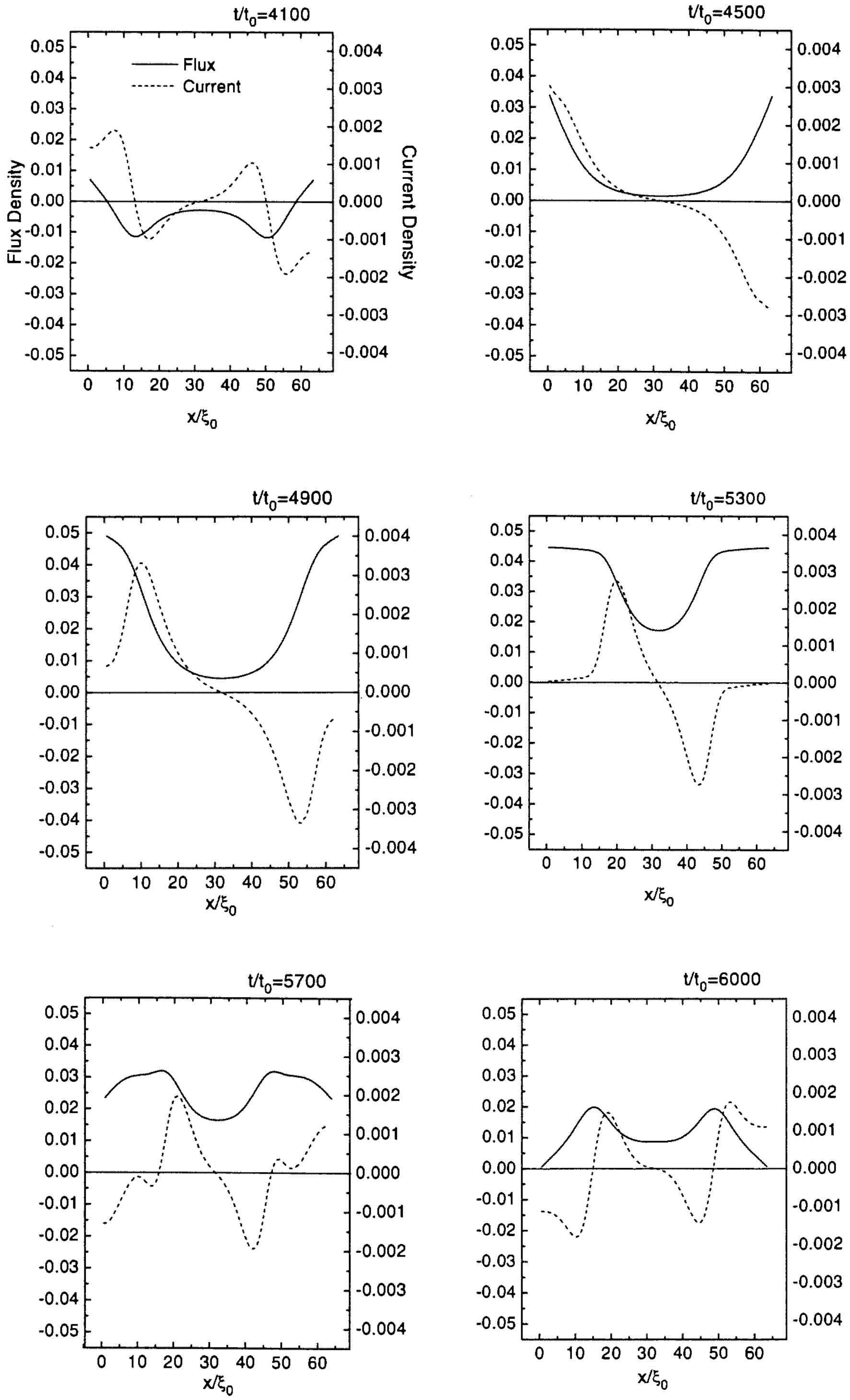

Figure 4. Time variations of profiles of the y-component of the current density (dashed lines) in units of $j_0 = cH_{c2}(0)/(4\pi\xi_0)$ along the x-axis at $y = 32\xi_0$ for $T/T_c = 0.91$ during one half of the period of the ac field. Profiles of b_z are also shown for comparison, as solid lines.

discussed elsewhere.

In conclusion, we have studied the ac magnetic response of type-II superconductors to the alternating magnetic field on the basis of numerical calculation of the TDGL equations. In particular, the temperature dependence of the ac susceptibility in the absence of the dc field with the amplitude and frequency of the ac field being fixed has been discussed. We have found a step-like change in χ_1', and a peak in χ_1'' and also in the third harmonic V_3 at a certain temperature near T_c. These results are in qualitative agreement with recent experimental data on high-T_c superconductors. Moreover, we have briefly discussed the relationship between these macroscopic behaviours of the system and the spatio-temporal behaviour of the local magnetic flux.

However, we should mention that there can be a big distance between simulations and experiments. This is because there are the following faults in the present model. Firstly, in real systems the ac response is strongly affected by pinning and thermal fluctuations, which are not in the model. Secondly, we have neglected the z-dependence of the problem. The present results, therefore, apply only to films, not bulk materials where the entanglement of flux lines may be important. These points will be discussed in future work.

Nevertheless, the present approach based on computer simulations of TDGL equations has been found to be potentially rich for throwing novel light on the problem studied here. For instance, the present model is applicable for discussing the validity of assumptions used in macroscopic and/or phenomenological models. Since the present study is still in a primitive stage, detailed simulations are now under way to allow discussion of a quantitative comparison of simulation results with theoretical results and experimental data obtained by not only the ac method but also the Hall probe method [18]. Moreover, many interesting problems still remain open, such as the dependence of the ac response on various physical parameters (e.g., the amplitude and frequency of the ac field, the dc field, bulk pinning and the sample geometry), and also the universal behaviour of the ac susceptibility. These problems are also now under consideration.

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Possible quantum gravity effects in a charged Bose condensate under variable e.m. field.

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Abstract

In the weak field approximation to quantum gravity, a "local" positive cosmological term $\mu^2(x)$ corresponds to a local negative squared mass term in the Lagrangian and may thus induce instability and local pinning of the gravitational field. Such a term can be produced by the coupling to an external Bose condensate. In the functional integral, the local pinning acts as a constraint on the field configurations. We discuss this model in detail and apply it to a phenomenological analysis of recent experimental results.

04.20.-q Classical general relativity.

04.60.-m Quantum gravity.

74.72.-h High-T_c cuprates.

Key words: General Relativity, Quantum Gravity, Experimental Gravitation, Bose Condensates, High-Tc Superconductors.

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The behavior of a Bose condensate – or more specifically of the Bose condensate of Cooper pairs within superconducting materials – in an external gravitational field has been the subject of some study in the past [1]. The presence in a superconductor of currents flowing without any measurable resistance suggests that a superconductor could be used as a sensitive detection system, in particular for gravitational fields. The possible back-reaction of induced supercurrents on the gravitational field itself has been studied too, in analogy with the familiar treatment of the Meissner effect. As one would expect, it turns out that the "gravitational Meissner effect" is extremely weak: for instance, it has been computed that in a neutron star with a density of the order of 10^{17} kg/m^3, the London penetration depth is ca. 12 km [2].

Such a penetration depth shows that the coupling of supercurrents to the classical gravitational field is extremely weak. The reason, of course, stems from the smallness of the coupling between gravity and the energy-momentum tensor of matter $T_{\mu\nu}$. One might wonder whether in a quantum theory of gravity – or at least in an approximation of the theory for weak fields – the Bose condensate of the Cooper pairs, due to its macroscopic quantum character, can play a more subtle role than as a simple contribution to the energy-momentum tensor.

In other words, we wonder if the macroscopic quantum coherence of the condensate can be taken into account at a fundamental level when computing the interaction between the superconductor and the external gravitational field. Results might then differ from those obtained from the gravitational coupling of "regular", incoherent matter. A similar approach has been earlier proposed by Weber in his studies of gravitational waves and neutrino fluxes detection [3].

In a quantum-field representation the condensate is described by a field with non-vanishing vacuum expectation value ϕ_0, possibly depending on the spacetime coordinate x. It is interesting to insert the action of this field, suitably "covariantized", into the functional integral of gravity, expand the metric tensor $g_{\mu\nu}$ in weak field approximation, and check if the only effect of $\phi_0(x)$ is to produce gravity/condensate interaction vertices proportional to powers of $\kappa = \sqrt{16\pi G}$. One finds that in general this is not the case; the quadratic part of the gravitational action is modified as well, by receiving a negative definite contribution. It can thus be expected that the condensate induces localized instabilities of the gravitational field, in a sense which we shall describe precisely in Section 2.

The present paper is based on the letter [4] and originates in part from previous theoretical work [5] and in part from recent experimental results ([6]; see Sections 3, 4) which show the possibility of an anomalous interaction, in special conditions, between the gravitational field and a superconductor. In Section 1 the theoretical model is introduced. In Section 1.1 we recall the role of a global cosmological term in the gravitational action. In Section 1.2 we show how a "local" positive cosmological term appears in the gravitational action due to the minimal coupling to a scalar field $\phi(x)$ with x-dependent vacuum expectation value $\phi_0(x)$, representing a Bose condensate with variable density. We define the "critical regions" of spacetime as those in which the overall sign of the cosmological term is positive. In Section 2 we discuss the gravitational instability induced by the condensate in the critical regions. We note that the "kinetic term" $R(x)$ in the gravitational lagrangian admits zero modes, and discuss qualitatively the effect of the instabilities in the Euclidean functional integral for the gravitational static potential energy [5]. In Section 3 we summarize the experimental findings reported in [6], trying to focus on the essential elements of an experimental setup which is quite complex. We add some remarks on the possible theoretical interpretations of these observations, according to the model with "anomalous" coupling between $h(x)$ and $\phi_0(x)$ introduced in the previous Sections. In Section 4 we describe our own experimental results and their interpretation. Finally, in Section 5 we discuss some issues of elementary character – but important from the practical point of view – concerning the overall energetic balance of the shielding process.

1 Bose condensate as "local" cosmological term in perturbative quantum gravity.

In this Section we show that a scalar field with a x-dependent vacuum expectation value, coupled to the gravitational field, gives a positive x-dependent contribution to the cosmological term. Our argument follows that given in [7].

1.1 Global cosmological term.

Let us consider the action of the gravitational field $g_{\mu\nu}(x)$ in its usual form:

$$S_g = \int d^4x \sqrt{g(x)} \left[\frac{\Lambda}{8\pi G} - \frac{1}{8\pi G} R(x) \right], \tag{1}$$

where $-R(x)/8\pi G$ is the Einstein term and $\Lambda/8\pi G$ is the cosmological term which generally can be present.

It is known that the coupling of the gravitational field with another field is formally obtained by "covariantizing" the action of the latter; this means that the contractions of the Lorentz indices of the field must be effected through the metric $g_{\mu\nu}(x)$ or its inverse $g^{\mu\nu}(x)$ and that the ordinary derivatives are transformed into covariant derivatives by inserting the connection field. Moreover, the Minkowskian volume element d^4x is replaced by $d^4x\,\sqrt{g(x)}$, where $g(x)$ is the determinant of the metric. The insertion of the factor $\sqrt{g(x)}$ into the volume element has the effect that any additive constant in the Lagrangian contributes to the cosmological term $\Lambda/8\pi G$. For instance, let us consider a Bose condensate described by a scalar field $\phi(x) = \phi_0 + \hat{\phi}(x)$, where ϕ_0 is the vacuum expectation value and $m_\phi|\phi_0|^2$ represents the particles density of the ground state in the non-relativistic limit (compare eq.s (8)-(10)). The action of this field in the presence of gravity is

$$S_\phi = \frac{1}{2}\int d^4x\,\sqrt{g(x)}\left\{[\partial_\mu\hat{\phi}(x)]^*[\partial_\nu\hat{\phi}(x)]g^{\mu\nu}(x) + m_\phi^2|\hat{\phi}(x)|^2 + m_\phi^2[\phi_0^*\hat{\phi}(x) + \hat{\phi}^*(x)\phi_0] + m_\phi^2|\phi_0|^2\right\}. \tag{2}$$

Considering the total action $(S_g + S_\phi)$, it is easy to check that the "intrinsic" gravitational cosmological constant Λ receives a contribution $\frac{1}{2}m_\phi^2|\phi_0|^2 8\pi G$.

Astronomical observations impose a very low limit on the total cosmological term present in the action of the gravitational field. The presently accepted limit is on the order of $|\Lambda|G < 10^{-120}$, which means approximately for Λ itself, that $|\Lambda| < 10^{-54}\ cm^{-2}$. (See [8] and references therein. We use natural units, in which $\hbar = c = 1$ and thus Λ has dimensions cm^{-2}, while G has dimensions cm^2; $G \sim L_{Planck}^2 \sim 10^{-66}\ cm^2$). This absence of curvature in the large-scale universe rises a paradox, called "the cosmological constant problem" [9]. In fact, the Higgs fields of the standard model as well as the zero-point fluctuations of any quantum field, including the gravitational field itself, generate huge contributions to the cosmological term – which, somehow, appear to be "relaxed" to zero at macroscopic distances. In order to explain how this can occur, several models have been proposed [10]. No definitive and universally accepted solution of the paradox seems to be at hand, if only because that would require a complete non-perturbative treatment of gravity – which for the moment, at least, is not feasible [11].

A model in which the large scale vanishing of the effective cosmological constant has been reproduced through numerical simulations is the Euclidean quantum gravity on the Regge lattice [12]. From this model emerges a property that could turn out to be more general than the model itself: if we keep the fundamental length L_{Planck} in the theory, the vanishing of the effective cosmological constant $|\Lambda|$, depending on the energy scale p, follows a law of the form $|\Lambda|(p) \sim G^{-1}(L_{Planck}\,p)^\gamma$, where γ is a critical exponent [13, 14]. We find no reason to exclude that this behavior of the effective cosmological constant may be observed in certain circumstances (see [7]). Furthermore, the model predicts that in the large distance limit, Λ goes to zero while keeping negative sign. Also, this property probably has a more general character, since the weak field approximation for the gravitational field is "stable" in the presence of an infinitesimal cosmological term with negative sign; conversely, it becomes unstable in the presence of a positive cosmological term (see [12] and Section 2).

1.2 Local cosmological term.

Summarizing, there appears to exist, independent of any model, a dynamical mechanism that "relaxes to zero" any contribution to the cosmological term. This makes the gravitational field insensitive to any constant term in the action of other fields coupled to it. Nevertheless, let us go back to the previously mentioned example of a Bose condensate described by a scalar field $\phi(x) = \phi_0 + \hat{\phi}(x)$. If the vacuum expectation value ϕ_0 is not constant but depends on the spacetime coordinate x, then a positive "local" cosmological term appears in the gravitational action S_g, and this can have important consequences. Let us suppose that $\phi_0(x)$ is fixed by external factors. Now, let us decompose the gravitational field $g_{\mu\nu}(x)$ as usual in the weak field approximation, that is, $g_{\mu\nu}(x) = \delta_{\mu\nu} + \kappa h_{\mu\nu}(x)$, where $\kappa = \sqrt{8\pi G} \sim L_{Planck}$. The total action of the system takes the form

$$S = \int d^4x \sqrt{g(x)} \left\{ \left[\frac{\Lambda}{8\pi G} + \frac{1}{2}\mu^2(x) \right] - \frac{1}{8\pi G} R(x) \right\} + S_{h\phi_0} + S_{\hat{\phi}}, \tag{3}$$

where

$$\begin{aligned}
\frac{1}{2}\mu^2(x) &= \frac{1}{2}[\partial_\mu \phi_0^*(x)][\partial^\mu \phi_0(x)] + \frac{1}{2} m_\phi^2 |\phi_0(x)|^2; && (4)\\
S_{h\phi_0} &= \frac{1}{2}\int d^4x \sqrt{g(x)}\, \partial^\mu \phi_0^*(x) \partial^\nu \phi_0(x) \kappa h_{\mu\nu}(x); && (5)\\
S_{\hat{\phi}} &= \frac{1}{2}\int d^4x \sqrt{g(x)} \Big\{ m_\phi^2 |\hat{\phi}(x)|^2 + m_\phi^2 \left[\phi_0^*(x)\hat{\phi}(x) + \phi_0(x)\hat{\phi}^*(x) \right] + \\
&\quad + \left[\partial_\mu \hat{\phi}^*(x) \partial_\nu \hat{\phi}(x) + \partial_\mu \phi_0^*(x) \partial_\nu \hat{\phi}(x) + \partial_\mu \hat{\phi}^*(x) \partial_\nu \phi_0(x) \right] g^{\mu\nu}(x) \Big\}. && (6)
\end{aligned}$$

In the action S, the terms $S_{h\phi_0}$ and $S_{\hat{\phi}}$ represent effects of secondary importance. The term $S_{h\phi_0}$ describes a process in which gravitons are produced by the "source" $\phi_0(x)$. The term $S_{\hat{\phi}}$ contains the free action of the field $\hat{\phi}(x)$, describing the excitations of the condensate and several vertices in which the graviton field $h_{\mu\nu}(x)$ and $\hat{\phi}(x)$ interact between themselves and possibly with the source. None of these interactions is of special interest here; they are generally very weak, due to the smallness of the coupling κ. The relevant point (eq.s (3), (4)) is that the purely gravitational cosmological term $\frac{\Lambda}{8\pi G}$ receives a local positive contribution $\frac{1}{2}\mu^2(x)$ that depends on the external source $\phi_0(x)$.

We shall use "critical regions" to designate those regions of spacetime where the following condition is satisfied:

$$\left[\frac{\Lambda}{8\pi G} + \frac{1}{2}\mu^2(x)\right] > 0. \tag{7}$$

As we shall see in Section 2, in these regions the gravitational lagrangian is unstable and the field tends to be "pinned" at some fixed values.

It is important to give a numerical estimate of the magnitude order of $\mu^2(x)$ in the case of a superconductor. To this end we recall that the Hamiltonian of a scalar field ϕ of mass m_ϕ is given by

$$H = \frac{1}{2}\int d^3x \left\{ \left|\frac{\partial\phi(x)}{\partial t}\right|^2 + \sum_{i=1}^{3}\left|\frac{\partial\phi(x)}{\partial x^i}\right|^2 + m_\phi^2|\phi(x)|^2 \right\}. \tag{8}$$

In our case ϕ describes a system with a condensate and its vacuum expectation value is $\langle 0|\phi(x)|0\rangle = \phi_0(x)$. Then in the Euclidean theory μ^2 is positive definite and we have

$$\langle 0|H|0\rangle = \frac{1}{2}\int d^3x\, \mu^2(x). \tag{9}$$

Thus μ^2 is connected to the coherent vacuum energy density. A prudent estimate gives, for a superconductor

$$\mu^2 > 10^{24}\ cm^{-4}. \tag{10}$$

As we saw in Section 1.1, a typical upper limit on the intrinsic cosmological constant observed at astronomical scale is $|\Lambda|G < 10^{-120}$, which means $|\Lambda|/8\pi G < 10^{12}\ cm^{-4}$. This small value, compared with the above estimate for $\mu^2(x)$, supports our assumption that the total cosmological term can assume positive values in the superconductor, and that the criticality condition can be satisfied in some regions. But in fact the positive contribution of the condensate is so large that one could expect the formation of gravitational instabilities in any superconductor or superfluid, subjected to external e.m. fields or not – a conclusion in contrast with the observations.

According to our discussion in Section 1.1, we may then hypothesize that the value of $\Lambda/8\pi G$ at small scale is larger than that observed at astronomical scale, and negative in sign, such that it would represent a "threshold" of the order of $\sim\ 10^{30}\ cm^{-4}$ for anomalous gravitational couplings. As we noted in Section 1.1, a negative intrinsic cosmological constant is allowed in models of quantum gravity containing a fundamental length. Given the small magnitude cited above, this threshold would not influence any other known physical process.

2 Gravitational instability and field "pinning" in the critical regions.

In this Section we discuss the gravitational instability induced by the condensate in the critical regions (7). We note that the "kinetic term" $R(x)$ in the gravitational lagrangian admits zero modes. Finally, we discuss qualitatively the effect of the instabilities in the Euclidean functional integral for the gravitational static potential energy [5].

Let us first consider the Einstein action with cosmological term (1) in the weak field approximation. We recall [15] that after the addition of a harmonic gauge-fixing, the quadratic part of the action takes the form

$$S_g^{(2)} = \int d^4x \, h_{\mu\nu}(x) V^{\mu\nu\alpha\beta}(-\partial^2 - \Lambda) h_{\alpha\beta}(x), \tag{11}$$

where $V^{\mu\nu\alpha\beta} = \delta^{\mu\alpha}\delta^{\nu\beta} + \delta^{\mu\beta}\delta^{\nu\alpha} - \delta^{\mu\nu}\delta^{\alpha\beta}$.

It is seen from (11) that in this approximation a cosmological term amounts to a mass term for the graviton, positive if $\Lambda < 0$ and negative (with consequent instability of the theory) if $\Lambda > 0$ [16]. Since in the presence of a condensate the sign of the total cosmological term depends on the coordinate x (eq.s (3)-(4)), we expect some "local" instabilities to form in the critical regions (7) in that case.

Such local instabilities were studied in [7], for the case of an Euclidean scalar field χ. Let us summarize very briefly the conclusions. If the squared mass term of the field χ is negative in some "critical" regions, then inside these regions χ tends to grow in order to minimize the action. However, this growth is limited by the gradient squared term in the lagrangian. One concludes that the field strength diverges in the critical regions only if the product of the imaginary mass by the size of the critical regions exceeds a certain constant.

In the case of perturbative quantum gravity, the situation is even more favourable to the formation of local instabilities, since the kinetic term $R(x)$ in Einstein action admits zero modes. Among these are not only the field configurations $h_{\mu\nu}(x)$ such that $R(x) = 0$ everythere, but also those which satisfy Einstein equations

$$R_{\mu\nu}(x) - \frac{1}{2} g_{\mu\nu}(x) R(x) = -8\pi G T_{\mu\nu}(x), \tag{12}$$

with $T_{\mu\nu}$ obeying the condition

$$\int d^4x \sqrt{g(x)} \, \mathrm{Tr}\, T(x) = 0. \tag{13}$$

(Note that for solutions of (12) one has $R(x) = 8\pi G \,\mathrm{Tr}\, T(x)$).

Condition (13) can also be satisfied by energy-momentum tensors that are not identically zero, but only if they have a balance of negative and positive signs, such that their total integral is zero. Of course, they do not represent any acceptable physical source, but the corresponding solutions of (12) exist nonetheless, and are zero modes of the action. (One can consider, for instance, the static field produced by a "mass dipole".) Clearly, there is no obstacle to the growth of the zero modes in the critical regions.

We shall admit that the growth of the gravitational field within the critical regions is limited by a positive higher order term in the action, that can be otherwise disregarded. The situation reminds that of a "$\phi^4 - \phi^2$" model (see Fig. 1), with the important difference that in the present case the field depends on x and is "pinned" only locally, in the critical regions [17].

How does this local pinning of the field influences the gravitational interaction of two masses m_1 and m_2 at rest? We recall the general formula for the static potential in Euclidean quantum gravity [5, 13, 18]:

$$U(L) = \lim_{T\to\infty} -\frac{\hbar}{T} \log \frac{1}{Z} \int d[g] \, \exp\left\{ -\hbar^{-1} \left[S_g + \sum_{i=1,2} m_i \int_{-\frac{T}{2}}^{\frac{T}{2}} dt \, \sqrt{g_{\mu\nu}[x_i(t)] \dot{x}_i^\mu(t) \dot{x}_i^\nu(t)} \right] \right\}, \quad (14)$$

where S_g is the gravitational action (1) and Z a normalization factor. The trajectories $x_1(t)$ and $x_2(t)$ of m_1 and m_2 are parallel with respect to the metric g. L is the distance between the trajectories, corresponding to the spatial distance of the two masses. (Of course, in the case we have in mind, m_1 should represent the Earth and m_2 a weighed sample, or conversely.)

Eq. (14) means that the interaction energy $U(L)$ of the two masses depends on the correlations between the values of the gravitational field on the "Wilson lines" $x_1(t)$ and $x_2(t)$. This dependence can be verified explicitly in the weak field approximation or through numerical simulations.

We can restate eq. (14) in the presence of the Bose condensate as

$$\begin{aligned} U[L, \mu^2(x)] \quad &= \quad \lim_{T\to\infty} -\frac{\hbar}{T} \log \frac{1}{Z} \int d[g] \int d[\hat{\phi}] \\ &\exp\left\{ -\hbar^{-1} \left[S[g, \hat{\phi}, \phi_0] + \sum_{i=1,2} m_i \int_{-\frac{T}{2}}^{\frac{T}{2}} dt \, \sqrt{g_{\mu\nu}[x_i(t)] \dot{x}_i^\mu(t) \dot{x}_i^\nu(t)} \right] \right\}, \quad (15) \end{aligned}$$

where $S[g, \hat{\phi}, \phi_0]$ is the total action defined in (3). If there are critical regions between the two Wilson lines, the field correlations are modified and in general the field "pinning" reduces $|U|$ (see also [7]). A detailed computation is in progress.

3 Experimental findings.

A recent experiment [6] has shown an unexpected interaction between the gravitational field and a superconductor subjected to external e.m. fields. In this Section we summarize the reported observations, trying to focus on the essential elements of an experimental setup which is quite complex. We add some remarks on the possible theoretical interpretations of these observations, according to the model with "anomalous" coupling between $h(x)$ and $\phi_0(x)$ introduced in the previous Sections. Attempts at an independent replication of the experiment have been started recently [19].

3.1 Summary of results with rotating disks.

The core of the experimental apparatus is a toroidal disk, 27 cm in diameter and made of high critical temperature (HTC) superconducting material. The disk is kept at a temperature below 70 K; it levitates above three electromagnets and rotates (up to ca. 5000 rpm) due to the action of additional lateral magnetic fields. All electromagnets are supplied with variable-frequency AC current.

Within certain frequency ranges one observes a slight decrease in the weight of samples hung above the disk, up to a maximum "shielding" value of ca. 1% (observed when the disk rotates at ca. 5000 rpm). A smaller effect, of the order of 0.1% or less, is observed if the disk is only levitating but not rotating. The percentage of weight decrease is the same for samples of different masses and chemical compositions. One can thus describe the effect as a slight diminution of the gravity acceleration g_E above the disk.

This effect does not seem to diminish with increased elevation above the disk: there appears to be a "shielding cylinder" over the disk (compare also [21, 20]), that extends upwards for at least 3 meters. The resulting field configuration is clearly non conservative (Fig. 2). An horizontal force at the border of the shielding cylinder has occasionally been observed, but it is far too small to restore the usual "zero circuitation" property of the static field. No weight reduction is observed under the disk.

The disk has a composite structure: the upper part has been treated with a thermal process which partially melts the grains of the HTC material and makes it a good superconductor, with high T_c (ca. 92 K) and high J_c (ca. 7000 A/cm^2). On the contrary, the lower part remains more granular and has a lower critical temperature (ca. 65 K). The aim of this double structure is to obtain good levitation properties, while also creating a layer in which considerable resistive effects can arise. Both characteristics appear to be necessary for the effect to take place: (1) the disk must be able to support intense super-currents; (2) a resistive layer must be present.

Another crucial feature of the experimental apparatus is the frequency spectrum of the applied e.m. field. Regardless of the reason for which the external e.m. field was originally employed, it seems clear to us that it plays a fundamental role in supplying the energy necessary for the apparent "absorption" of the gravitational field in the disk (compare energetic balance considerations in Section 5). Experimentally one observes [6] that the maximum shielding value is obtained when the coils are supplied with high frequency current (of the order of 10 MHz).

Transferring power to the disk is inherently not very efficient. This represents one of the most serious problems to overcome in order to achieve a stable shielding effect, especially for heavy samples. Otherwise, large amounts of refrigerating fluid will be needed to keep the disk from overheating and exiting the superconducting state. Remember that the maximum shielding values have been observed under conditions which seem to trigger the production of heat. This makes clear why a disk made of HTC material is important: although a low-temperature superconductor could also reach the critical density conditions, its specific heat is probably too small to maintain the essential conditions while allowing adequate power transfer.

3.2 Interpretation.

We have already stressed in our analysis [4] that an interpretation of the reported effect in the framework of General Relativity, as due to repulsive post-newtonian fields produced by the super-currents [22], is untenable, since the magnitude order of the effect is far too large [23].

Our interpretative model of the experimental results is based on the "anomalous" coupling between Bose condensate and gravitational field described in the previous Sections. In this model the essential ingredient for the shielding is the presence of strong variations of the Cooper pairs density in the disk: *we assume that such variations produce small regions with higher density, where the criticality condition (7) is satisfied*. It is thus necessary to understand, from this point of view, how the experimental parameters summarized above combine to produce such critical conditions.

A correct theoretical interpretation should also suggest alternative experimental settings and possibly lead to a simplified version of the experiment, still giving an observable shielding effect. Some steps toward such a partial replication have been taken by the authors (see below, Section 4, and the Appendix).

We recall that the HTC toroidal disk has a composite structure, with two layers as described in Section 3.1. At the operation temperature (slightly below 70 K) the supercurrents, which circulate without any resistance and take the high value $J_c \sim 7000\ A/cm^2$ in the upper part of the disk, are essentially zero in the lower part. The interface represents a sort of boundary for a fluid motion: the intensity of the supercurrents, which flow parallel to the interface, falls to zero at the interface itself (see Fig. 3).

For our purposes we can regard the supercurrents as a perfect fluid and apply the corresponding equations of fluid dynamics. (Phenomenological theories of superconductivity based on the two-fluids model are largely independent from the detailed microscopic mechanism which produces superconductivity and which is not well known yet in the case of HTCs.) The fluid density – i.e., the density of the Bose condensate – is subjected to local variations, or the fluid is compressible. In other words, while the *average* fraction of superconducting charge carriers in the material depends only on the ratio T/T_c and is small at temperatures about 70 K, usually not exceeding a few %, locally there can be for some reason a concentration of superconducting charge carriers, up to a maximum density fixed by the total charge density of the lattice.

Let now v represent the local velocity of the superconducting fluid, ρ its local density and m the mass of a superconducting charge carrier. If the gradient of T can be disregarded and the flow is irrotational (as usually assumed for superfluid motion) the following differential equation holds [24]

$$\mathrm{grad}\left(\frac{1}{2}v^2 + \frac{1}{m}V\right) = -\frac{T}{m}\,\mathrm{grad}(\log\rho), \tag{16}$$

where V is the external potential, which can be set to zero in the following, since it is almost constant over small distances and in the present case we apply eq. (16) to a very thin region above the interface.

Assuming that ρ and v depend only on the coordinate z, the solution of (16) is

$$\rho(z) = \rho_0 \exp\left[-\frac{1}{T}\left(\frac{1}{2}mv^2(z)\right)\right]. \tag{17}$$

In order to find ρ as a function of the distance z from the interface we need to know the dependence $v(z)$. Far above the interface, v takes an approximately constant value v_{max}. We shall assume that v vanishes at the interface, due to ohmic resistance, and that v grows, close to the interface, as a power of z. The behavior of $\rho(z)$ is then shown in Fig. 4.

It is seen that the condensate density ρ takes an higher value at the interface than far above it, in the bulk of the "good" superconducting material. This fact is rather intuitive and could have been predicted without use of the fluid equation. Given a "threshold" value ρ_c of the density, there will be a thin layer $0 < z < z_c$ close to the interface in which $\rho_c < \rho(z) < \rho_0$. This layer corresponds to a critical region as defined in Section 1.2. Below the interface ($z < 0$), ρ vanishes. (In practice however, since the interface is not very clear-cut, the curve $\rho(z)$ will go smoothly to zero for $z < 0$.)

The relative velocity of the supercurrent with respect to the lower part of the disk is essentially determined by the rotation frequency of the disk [25], because the average velocity of the charge carriers in the supercurrent is on the order of 10^{-5} m/sec, while the tangential velocity due to rotation is much higher, on the order of 10 m/sec. Let us work out this estimate in more detail. The critical current density in the upper layer of the disk is $\sim 10^8$ A/m^2. Taking a density of charge carriers of 10^{32} m^{-3}, with an elementary charge of $\sim 10^{-19}$ C we find $v = J/\rho \sim 10^{-5}$ m/sec. On the other hand, when the disk is rotating at angular frequency $\omega \sim 5000$ $rpm \sim 500$ sec^{-1}, a point at distance 10 cm from the rotation axis has tangential velocity $v = \omega r \sim 50$ m/sec.

We shall briefly discuss in Section 4.1 how conditions similar to those described above, which are present in "stationary form" at the interface in the rotating composite superconducting disk used in [6], are reproduced for short time intervals in our own experiment.

4 Our experiment.

One of us (J.S.) has recently succeeded in partially reproducing the weak gravitational shielding effect described in the previous Section. The experimental setup was suggested by the theoretical model outlined in Sections 1-3. It was also designed to eliminate, as far as is possible, any non-gravitational disturbance, and to show a precise temporal correspondence between actions taken on the HTC disk and the weight reduction of the sample/proof mass. Although the observed weight reduction was large enough to be clearly distinguished from the noise (of the order of 1 % or more), it was detected only in transient form, lasting up to ca. 3 s. This happened because the weight reduction was coincident with the superconducting transition of the HTC disk, which occurred quite rapidly when the disk warmed up over its critical temperature.

Our earlier experimental setup is described in the Appendix. An improved setup allowed us to run more than 400 trials with an heavier proof mass (a glass rods bundle – total weight 63 g), accumulating better statistics. Approximately 10 % of the trials gave positive result, i.e., a clear transient reduction in the weight of the proof mass. This apparently random behavior signals that some of the conditions which are necessary to trigger the effect are not well under control yet. In particular, we found that the duration of the superconducting transition is very crucial: if the transition is too quick or too slow with respect to certain criteria, no effect is observed. The duration of the transition, in turn, depends strongly on the thermal conditions of the disk, and the latter can be controlled only with limited accuracy. A closer discussion of this point can be found in Section 4.1.

Our improved setup did not comprise the AC generator anymore. Thus error analysis is further simplified. One only needs to consider the parasitic effects of buoyancy and molecular diamagnetism. For both error sources, upper limits can be set according to the discussion in [6] and these limits are much smaller (by a factor 20 at least) than the observed effect.

As mentioned above, the transient reduction in the weight of the proof mass was always coincident with the thermal transition of the YBCO disk from the superconducting to the non-superconducting state. This was checked as follows.

A dewar flask with an inside diameter of about 3 *cm* and 14 *cm* deep allows to observe the experiment from the side by virtue of the fact that about 2.5 *cm* of the silvering, inside and out, has been removed when manufactured (see Fig. 5). The top of a hollow cylinder of polyethylene is flush with the bottom of the removed silvering. This cylinder supports, through two parallel bamboo sticks, a 2.5 *cm* by 1.3 *cm*, 0.3 *cm* thick samarium cobalt permanent magnet with an $MGOe$ factor of approximately 18. The magnet is even with the bottom of the removed silvering.

The dewar contains liquid nitrogen, as to half fill the clear observation area. This leaves about 1.3 *cm* of empty dewar with the permanent magnet at the bottom. After filling, all is allowed to cool down. A LEVHEX, almost-single-crystal, "pinning type" YBCO hexagon (2.0 *cm* from side to side) is tied to a cotton string and lowered into a second dewar to cool. When the LEVHEX is chilled, it is lowered into the first dewar. The levitation effect is pronounced and a piece of bamboo is used to push the hexagon down and leave it at approximately 0.6 *cm* above the magnet, as opposed to ca. 2.0 *cm* of its highest equilibrium position. The hexagon is well pinned and the familiar "tied to little springs" effect is well in evidence.

The detection system (see Fig. 6) is quite similar in principle to that described in the Appendix. Namely, a 33 *cm* by 51 *cm* glass plate on ring stand clamps is interposed between the dewar and a 63 *g* proof mass made of a hexagonal bundle of 7 rods, each 10 *cm* long and 0.6 *cm* in diameter. The string is tied to a dry 1 *cm* by 1 *cm*, 200 *cm* long wooden beam. The beam acts as a balance and has a 3 *mm* hole drilled in the middle. A 1 *mm* stainless steel pin in an aluminum stirrup serves as a pivot in the middle. The purpose of the beam is to place a

“Mettler 300” scale (300 g full scale, 0.01 g resolution) at least 180 cm from the dewar. The proof mass is directly over the levitating hexagon and the far end of the beam has an excess weight (aluminum blocks tied by cotton string) which rests on the scale. Once the whole is set up the scale is tared to leave a weight of 44.0 g. In order to eliminate any electrostatic artifact, an aluminum screen and a brass screen are taped to the glass plate placed between the dewar and the proof mass.

As the liquid nitrogen boils away the temperature of the LEVHEX rises. We see this evidenced by a slight reduction in the height of levitation at first, and, finally, there is no levitation at all. Exactly during this phase, which may last typically between 5 and 10 s in the different runs, we observe a transient reduction in the weight of the proof mass as indicated by the counterweight on the balance. In a “positive” run the measurement on the scale generally goes from 44.0 to 46-47 g and then returns to baseline after 2-3 s. This corresponds to a reduction in the apparent weight of the proof mass.

4.1 Interpretation.

A mixed state with locally-enhanced condensate density, similar to that present at the interface of the composite rotating disk (Section 3.2) forms, for a short time interval (a few seconds), also when a good-quality, single-phase HTC superconducting disk warms up above its critical temperature and goes from the superconducting to the normal state.

It is known that at the transition to the normal state some small non-superconducting regions first appear in the superconducting material, and then they gradually grow. Now, if strong circulating supercurrents had been previously induced in the material, these currents will rapidly decay at the transition. However, there will be during the transition a short intermediate phase in which part of the supercurrents still circulate, through those regions in which the material is still superconducting (Fig. 7). During this phase the flow of the supercurrents can still be described by a perfect fluid model like in Section 3.2. The non-superconducting regions act as boundaries for the flow and the resulting pattern for the condensate density will exhibit roughly similar features to those we found earlier: namely, the condensate density will be higher near the resistive obstacles, where the velocity must be smaller. Clearly if the superconducting transition is “too slow”, and the system is allowed to reach equilibrium, the critical density may be not achieved anywhere.

Unlike in the case of the rotating toroid, the whole bulk of the HTC disk is involved in this case. It is crucial for the occurrence of the effect that the supercurrent present in the disk at the transition be very high and that the transition width ΔT_c be small. This requires an excellent HTC ceramic material.

The application of AC magnetic fields may allow some control on the transition rate. We are presently improving our earlier apparatus (see the Appendix) in this direction. The method described above, however, can be used to demonstrate the effect in a very clean way.

5 Energetic balance.

It is necessary now to discuss some issues of elementary character – but important from the practical point of view – concerning the overall energetic balance of the shielding process.

In general energy must be supplied in order to reduce the weight of an object, because the potential gravitational energy of the object has negative sign and is smaller, in absolute value, in the presence of shielding. However, since the field is non-conservative, it is certainly wrong to compute the difference in the potential energy of an object between the interior and the exterior of the shielding cylinder by evaluating naively the difference (which turns out to be huge) between an hypothetical "internal potential"

$$U = -\frac{GMM_E(1-\alpha)}{R_E} = -Mg_E R_E(1-\alpha), \tag{18}$$

and an "external potential" $U = -Mg_E R_E$. (Here M is the mass of the object, R_E the Earth radius, M_E the Earth mass and α the "shielding factor", $\alpha \sim 0.01$.)

Moreover, the gravitational fields with which we are most familiar, being produced by very large masses, are relatively insensitive to the presence of light test bodies; thus, it makes sense in that case to speak of a field in the usual meaning: while a body falls down, we do not usually worry about its reaction on the Earth. But in the present case, the interaction between the shielded object and the external source (that is, the system [Bose condensate+external e.m. field], which, by fixing the constraints on the gravitational potential h, produces the shielding), is very important [26].

Let us then ask a provocative question, suggested by the experimental reality: if the superconducting disk is in a room and the shielding effect extends up to the ceiling, should we expect the disk and all the shielding apparatus to feel a back reaction? (And possibly an even stronger one if the ceiling is quite thick or if there are more floors above?) The most reasonable answer is this: since the ceiling is very rigid, the experimental apparatus is not able to exert any work on it and thus does not feel its presence.

To clarify this point, imagine that we hang over the superconducting disk a spring of elastic constant k and holding a body of mass M at rest. Then we operate on the disk with proper e.m. fields and produce the shielding effect with factor α. Now, the gravity acceleration over the disk becomes $g_E(1-\alpha)$. If the shielding effect is obtained quickly, the mass should begin to oscillate, otherwise it should rise by an height of $\Delta x = \alpha g_E M k^{-1}$, while remaining in equilibrium. In any case, since the kinetic energy and the potential energy of a harmonic oscillator in motion have the same mean value, it is legitimate to conclude that the work done by the shielding apparatus on the system [mass+spring] is on the order of

$$\Delta E \sim k(\Delta x)^2 \sim (\alpha g_E M)^2 k^{-1}. \tag{19}$$

This example shows that the work exerted by the apparatus on a sample being "shielded" will depend in general on the response of the sample itself. Only if the object being shielded can respond to the effect will work be done.

At this point we can estimate how much energy is needed to achieve critical density in one region of the condensate of cross section σ. If σ_{sample} is the projection of the sample on the disk, this energy is given by

$$\Delta E_\sigma = \frac{\sigma}{\sigma_{sample}} \Delta E \sim \frac{\sigma}{\sigma_{sample}} (\alpha g_E M)^2 k^{-1}. \tag{20}$$

This energy must be supplied by the external variable e.m. field.

In conclusion, we must expect in general an interaction between the partially shielded samples and the shielding apparatus. The energy needed to shield a sample depends on the mass of the sample itself and on the way it is constrained to move. In particular, we deduce from eq. (19) that if we want to detect the shielding effect by measuring the deformation of a spring (and do this with the minimum influence on the shielding apparatus) we should use, as far as is allowed by the sensitivity of the transducer, a spring with a high rigidity coefficient k.

Acknowledgments.

We are very grateful to E. Podkletnov for advice and encouragement. We are very much indebted to J.R. Gaines, Vice President of Superconductive Components, Columbus, Ohio, USA, who supplied the HTC disk.

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[17] Short-distance regulators or higher-order terms, analogous to a "ϕ^4" term in the scalar field case, are present in several models of quantum gravity [10,12]. Note that the size of our hypothesized critical regions can be regarded as macroscopic with respect to the scale where conformal fluctuations of the metric or R^2-terms become important. For this reason, we believe that an approach based upon the Euclidean weak field approximation + regulator is appropriate.

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[26] Because of this, considerations involving the local energy density of the gravitational field, which can be properly defined for weak fields, are not helpful in the present case.

Appendix: earlier setup.

Our first experimental setup consisted of (a) a hexagon-shaped YBCO 1" (2.5 *cm*) superconducting disk, 6 *mm* thick; (b) a magnetic field generator producing a 600 *gauss*/60 *Hz* e.m. field; (c) a beam balance with suspended sample.

The beam is made of bamboo, without any metal part, coming to a point on one end (24.6 *cm* long, weight 1.865 *g*). The sample is made as follows. A cardboard rectangle (16 *mm* by 10 *mm* by 0.13 *mm*) is suspended from the balance with 2.8 *cm* of cotton string. A polystyrene "pan" (7.2 *cm* by 8.7 *cm* by 1.7 *mm*) is attached with paper masking tape to the cardboard rectangle. The total sample assembly (with string, cardboard, tape) weighs 1.650 *g*.

The balance is suspended from the end of a 150 *cm* wood crossbeam by ca. 30 *cm* of monofilament fishing line attached to the balance's center of mass (5.5 *cm* from the end where the sample is attached). The other end of the crossbeam is firmly anchored by a heavy steel tripod. Thermal and e.m. isolation is provided by a glass plate (15 *cm* by 30 *cm*, 0.7 *cm* thick) with a brass screen attachment. This plate-and-brass-screen assembly is held about 4.5 *cm* below the sample by a "3-finger" ring stand clamp. A straightsided, 14 *cm* diameter, 25 *cm* deep dewar with ca. 10 *cm* of liquid nitrogen is used to cool the superconducting disk below its critical temperature, and is removed from the experiment area before the trial.

The experimental procedure comprises the following steps.

1. The YBCO superconductor is placed in a liquid nitrogen bath and allowed to come to liquid nitrogen temperature (as indicated when the boiling of the liquid nitrogen ceases). The superconductor will remain below its critical temperature (about 90 *K*) for the duration of the trial (less than 20 seconds).

2. The disk is then removed from the bath and placed on a strong NdFeB magnet to induce a supercurrent. The Meissner effect is counteracted by a wooden stick. The superconducting disk has a cotton string attached to it to assist handling.

3. The disk and wooden stick assembly is placed on the AC field generator, about 33 *cm* below the isolation plate and about 40 *cm* below the sample. The AC field generator is then cycled for ca. 5 seconds with 0.75 *sec* equal-time on/off pulses. Prior to a run the sample is centered to be over the middle of where the disk will finally be, on the AC field generator.

One observes that while AC current is flowing through the generator the balance pointer dips 2.1 mm downward. When the AC field generator is pulsed with no superconductor present, there is no measurable pointer deflection. Also air flows do not cause any measurable deflection. The whole procedure is well reproducible.

The weight difference required to raise the sample by 2.1 mm was then found to be 0.089 g. This was measured taking advantage of the fact that the suspension wire produces a small torque on the balance beam toward the equilibrium position: the balance pointer was found to raise 2.1 mm upward when a weight of 0.089 g was placed above the sample.

FIGURE CAPTIONS

1. *Typical double-well potential of a* $(\phi^4 - \phi^2)$ *field system.*

   The curve A represents a familiar "ϕ^2" potential, corresponding to a field with positive squared mass term. The curve B represents the same "ϕ^2" potential, to which a "ϕ^4" term has been added. The lowest energy excitations are nearly the same for A and B. In C, the sign of the "ϕ^2" term has been reversed ($(\phi^4 - \phi^2)$ potential). Now, in the lowest excitations the field is pinned to finite values distinct from zero.

2. *Non-conservative character of the "modified" field above the superconducting disk.*

   The "modified field" described by Podkletnov, with an infinite cylinder-like shielding zone over the disk, is clearly non-conservative. This means that if a proof mass goes along a closed path (up within the shielding zone, and down outside), the gravitational field exerts a net positive work on it.

   From the formal point of view, this means that the observed static field is not the gradient of a gravitational potential, even though the Einstein equation for the connection (divΓ=0) still holds true.

   Physically, this property is due to the ("anomalous") coupling of the gravitational field with the external e.m. field, coupling that is mediated by the Bose condensate in the superconducting disk. The mechanical energy that a proof mass gains when it goes along the closed circuit is furnished by the external e.m. field.

3. *Schematic diagram representing the velocity distribution of the superconducting charge carriers in the upper layer of the toroidal disk (B) during rotation.*

   The lower layer (A) is not superconducting at the temperature of operation (slightly below 70 K). The *relative* velocity of the superconducting charge carriers with respect to the interface between the two layers is represented by thick arrows. It grows from zero to some velocity v_{max} according to a power law (compare Fig. 4).

   This is a side view. In stationary conditions, the relative velocity has no component along the vertical direction z. We suppose that the disk is rotating clockwise, so the short arrow means in reality that the superconducting charge carriers near the interface are almost co-rotating with the disk; the carriers farther away from the interface "follow slower", thus with larger relative velocity, up to v_{max}.

4. *Variation of the condensate density in the upper layer of the disk as a function of the distance from the interface, according to the perfect-fluid model.*

   For the definition of the coordinate z and a qualitative description of the velocity pattern compare Fig. 3.

   The curve $v(z)/v_{max}$ shows for illustration purposes a quasi-linear growth of the velocity of the superconducting charge carriers with increasing distance from the interface, followed by saturation to the value v_{max}. The curves A, B, C represent the behavior of the local condensate density $2\rho/\rho_0$ (the factor 2 is for graphical reasons) according to eq. (17), for the following specific cases:

   A: $v(z)/v_{max} \sim z^{1/2}$

   B: $v(z)/v_{max} \sim z$

   C: $v(z)/v_{max} \sim z^{3/2}$

   It is seen that the condensate density achieves its maximum value for $v = 0$ and its minimum for $v = v_{max}$.

   The line D represents the threshold condensate density ρ_c necessary for anomalous coupling. Z_c represents the thickness of the critical region of the condensate if the velocity depends on z like in A (the generalization to the cases B and C is obvious). This means that in the thin layer $0 < z < z_c$ close to the interface one has $\rho_c < \rho(z) < \rho_0$, or the layer is a "critical region". Note that the value of the ratio ρ_c/ρ_0 as depicted above and the z-scale are just for illustration purposes.

5. *Scheme of our [magnet+LEVHEX] setup.*

   A: Dewar flask (height 14 *cm*, inside diameter 3 *cm*).

   B: Part of the dewar (height 2.5 *cm*) where the silvering has been removed to allow side observation of the levitating YBCO hexagon (E).

   C: Polyetilene tube supporting the magnet (D) through two parallel bamboo sticks.

   D: samarium cobalt permanent magnet (2.5 *cm* by 1.3 *cm*, 0.3 *cm* thick).

   E: LEVHEX "pinning type" YBCO hexagon (2.0 *cm* from side to side).

6. *Detection system for the demonstration experiment of transient shielding effect at the superconducting transition.*

   A: Dewar flask (see details in Fig. 5) with LEVHEX levitating above magnet.

   B: Glass screen, with brass and aluminum foils, to shield proof mass from air flows and electrostatic fields.

   C: Proof mass: bundle of 7 glass rods, each 10 *cm* long and 0.6 *cm* in diameter; total weight 63 *g*.

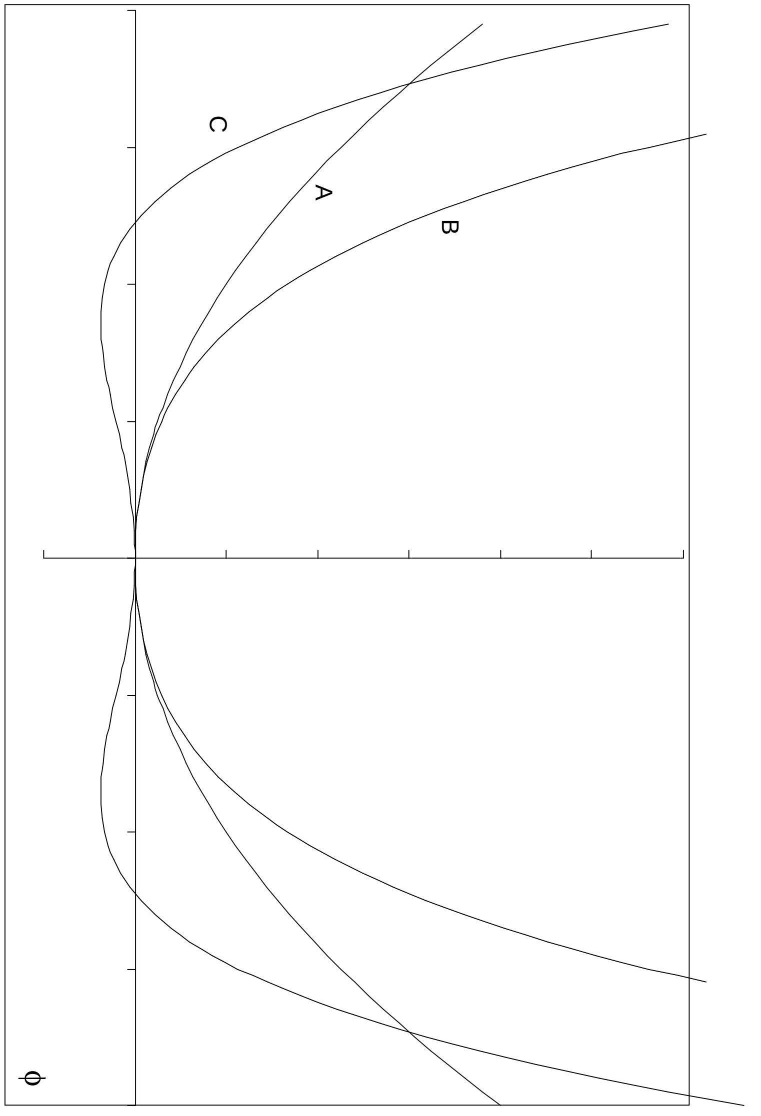
   D: Wooden balance beam, 1x1x200 *cm*.

   E: Mettler 300 balance, 0.01 *g* resolution.

7. *Velocity and density pattern of the superconducting charge carriers in a bulk disk at the transition (dark: critical regions).*

   At the transition to the normal state some small non-superconducting regions first appear in the superconducting material, and then they gradually grow. If strong circulating supercurrents had been previously induced in the material (top), these currents will rapidly decay at the transition. However, there will be during the transition a short intermediate phase in which part of the supercurrents still circulate, through those regions in which the material is still superconducting (bottom).

   During this phase the flow of the supercurrents can still be described by a perfect fluid model like in Section 3.2. The non-superconducting regions act as boundaries for the flow and the resulting pattern of the condensate density will exhibit roughly similar features to those we found earlier: namely, the condensate density will be higher near the resistive obstacles, where the velocity must be smaller.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Engineering Analysis of the Podkletnov Gravity Shielding Experiment

Peter L. Skeggs
7 Nov 1997

Abstract

Eugene Podkletnov's recent work [1] involving the supposed shielding of gravity by means of a rotating superconductor in a high frequency magnetic field has attracted much attention. At least one group, Delta G at NASA Marshall Space Flight Center and University of Alabama Huntsville, is currently working on a reproduction of his experiment. However, this is quite difficult due to the lack of engineering detail. Here, the author pulls together important information from the text and a figure of Podkletnov's paper, then makes estimates of the magnetic field configuration of the coils used to levitate the superconducting disk via the Meissner effect. An upper limit magnetic flux density of 850 gauss near the poles of the coils is calculated. Finally, this estimate for the magnetic flux density is used to calculate the expected acceleration on a test sample due to the gravitomagnetic and gravitoelectric fields postulated by Li and Torr [6] -- at most $145*10^{-6}$ cm/s^2. Although not large enough to explain Podkletnov's results, it should be detectable by NASA's gravimeter.

Summary of Salient Points

1. Section 1, second paragraph: "a new installation was built... magnetic fields up to 2 T and frequencies up to 10^8 Hz..."
1. Section 2, first paragraph: "The shielding superconducting element was made of dense, bulk, almost single-phase YBCO and had the shape of a toroidal disk with an outer diameter of 275 mm, an inner diameter of 80 mm, and a thickness of 10 mm... A thin (1 mm) foil of magnetic material was attached (without electrical contact) to the upper surface of the disk, using hot-melt adhesive, to facilitate rotating the disk as described below, especially at the initial stages of rotation."
2. Section 3, first paragraph: "The toroidal disk was placed inside a cryostat equipped with a set of three coils (Fig. 3) that could keep it levitating when it reached the superconducting state."
3. Section 3, second paragraph: "High-frequency electric current (10^5 Hz) was first sent to the two main solenoids around the disk to initiate an internal current in the ceramics while the disk was still at room temperature." He cools the disk, then "the main solenoids were switched off. After this, the high-frequency current *[implying there is just one high frequency current in question, which is 10^5 Hz]* was sent to the coils below the disk, and the superconductor raised up (at least 15 mm..."
4. Section 3, third paragraph: "Then a small current (10^5 Hz) was sent to the main solenoids, causing the disk to begin rotating counter-clockwise with increasing speed. The rotation speed was increased up to 5000 rpm. At this point the current in the rotating coils was of the order of 8-10 A. (The diameter of the wire of these coils is 1.2 mm). This current was supplied by powerful high-frequency generators usually employed for induction heating and quenching of metals."

Wire Size Analysis

At first, it seems that 1.2 mm diameter wire would be too small to carry such large currents. A wire table [2] was consulted. A 1.2 mm diameter wire, which is the same as a diameter of 47.2 mils or around 16 gauge, is recommended to carry at most 1.7 A. Of course, this is a conservative limit to prevent heat buildup and resistive losses.
Another data point is what the NEC [3] recommends for 14 gauge wire; it's allowed for circuits carrying 15 A, 60 Hz, at 115 VAC in residential wiring applications. This would be equivalent to 9 A for 16 gauge wire. So perhaps 1.2 mm is not unreasonable.
A third data point is to calculate the skin depth [4] of copper wire at 10^5 Hz:

$$d_p = (2 / (w * u * s))^{0.5} \quad (1)$$

where w = omega = 2 pi * 10^5, u = mu = magnetic permeability of copper = 4 pi * 10^{-7}, and s = sigma = conductivity of copper = 5.8 * 10^7 mho/m. This gives d_p = 0.21 mm. A rule of thumb is to use a conductor that is 5 times the skin depth, so a 1.05 mm wire should suffice. Because there is an inversely proportional relationship between frequency and skin depth, this is also acceptable up to the maximum operating frequency of 10^8 Hz.

Analysis of Levitation Coils

Unfortunately, Podkletnov's text gives no data as to how many turns of wire are in each coil, nor the dimensions of the coil, so a calculation of it's inductance or magnetic field strength seems difficult to do. However, if one assumes that fig. 3 of his paper is accurate, then dimensions of the coils can be inferred. Giovanni Modanese has suggested as much to the author previously [5].

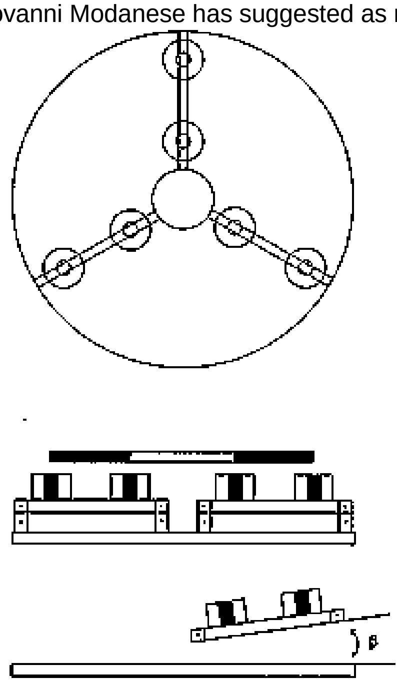


Figure 3 from Podkletnov's cond-mat/9701074.

Fig. 3 shows that the 3 coils are actually each made of 2 coils connected to a roughly U-shaped core which positions one coil at the outer diameter of the disk and the other coil at the inner diameter. This forms a magnetic circuit that one might suppose has one pole (say the north) emitting flux at the outside diameter and the other pole collecting flux at the inner diameter; the poles switch direction every half cycle of applied AC. Because the flux would be partially or mostly expelled from the superconductor, the flux lines would travel radially along the bottom face of the toroid.

Since the outer diameter of the toroid is 275 mm, and the inner is 80 mm, I estimate (by measuring a printout of fig. 3, where 1 mm on paper = 6.25 mm in real life) the centers of the two coils in each of the 3 supporting solenoid structures to be 97.5 mm apart. Each coil body is 40.6 mm in diameter on the outside, and perhaps 12.5 mm inside (the diameter of the vertical piece of the magnetic core material). Each coil body is also ~25 mm tall.

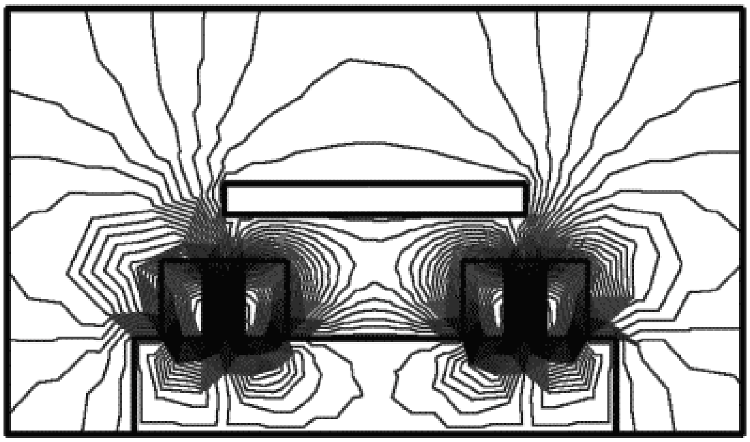
From these dimensions, plus the diameter of the wire, one can estimate the number of turns. The cross-sectional area of one half of a coil is (40.6/2 - 12.5/2) * 25 = 351 mm^2. The cross-sectional area of a 1.2 mm wire is 1.13 mm^2. So, assuming optimal packing, there could be at most 310 turns in each coil.

The current density through one half of the coil is:

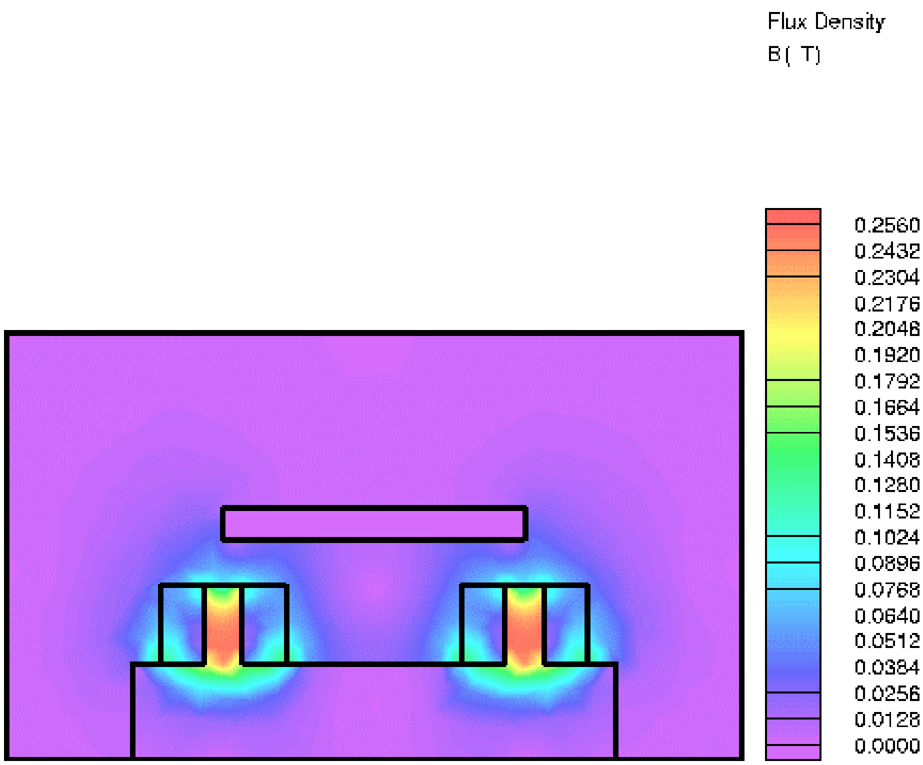
$$J = I * n / A \qquad (2)$$

where I is the current equal to 10 A, n is the number of turns, and A is the cross sectional area, resulting in a current density J = 8.83 A / mm^2, or 8.83 * 10^6 A / m^2. This number was entered into QuickField (a finite element analysis program for electric and magnetic fields), assuming that the current points in to the page for the left half of the left coil, out for the right half of the left coil, out for the left half of the right coil, and in for the right half of the right coil (so the two B fields generated are of opposite direction), the core is steel with a relative permeability of 5000, for the geometry consisting of 2 coils and a connecting bar of core material, and using dimensions of each part estimated from Podkletnov's fig. 3.

The program found that the B field generated 15 mm above a pole is a maximum of about 400 gauss, with H about 32700 A / m; even immediately adjacent to the core material at the top center of a coil, the maximum B is 850 gauss, with H about 67900 A /m. Note that these results are using QuickField in the magnetostatic or DC condition.



Magnetic Flux Lines around 1/2 of toroidal disk created by one solenoid assembly. Note the expulsion of flux from the superconductor.



Map of magnetic flux density B around the assembly. Note the zero B field inside the superconductor.

Gravitomagnetic Force Estimate

Note that the magnetic flux density applied across the radius of the superconductor is above the lower critical field (B_{c1}) for YBCO which is ~ 60 gauss. This implies that flux vortices should be formed which run horizonally through the radius of the disk. This also implies using the Li/Torr theory [6] for the generation of a gravitomagnetic field by the coherent rotation of lattice ions, that a Bg field with a radial component should be generated. Assuming that this is large outside the disk (which is highly speculative), and that there exists a gravitational analog of the Lorentz force [7]

$F = m * (E_g + v \times B_g)$ (3)

where m is the mass of a test sample, E_g is the normal gravitational pull of the Earth plus possibly an induced gravitoelectric field, v is the velocity of the test sample relative to the superconductor, and B_g is the gravitomagnetic field generated by the rotating ions. This should generate a vertically oriented force on a test sample, since v points in the direction of a tangent to the circumference of the disk, B_g points radially, and thus their cross product points vertically. This is exactly what Podkletnov has reported: the vertical change in apparent weight of an object.

The problem with this explanation is the magnitude of B_g. Li/Torr predict a value (eq. 3.8, p. 381) that is approximately

$$B_g = 10^{-9} B_o \qquad (4)$$

where B_o is the applied magnetic field. The velocity v at the outer radius of the 275 mm disk rotating at 5000 rpm, is 7200 cm / s. With B_o of 0.24 Tesla (400 gauss for each of 6 coils), B_g is 2.4 * 10^{-10} / s. This results in an acceleration term due to the gravitomagnetic field (the right hand inner term of eq. 3) of only 1.7 * 10^{-6} cm / s^2, compared to the acceleration due to gravity of the Earth of approximately 980 cm / s^2. So, assuming the 10^{-9} coupling term is accurate, this model does not explain Podkletnov's claimed 0.05% to 2.1% loss of weight in his samples. However, the magnitude of this change of 1.7 * 10^{-6} cm / s^2 is well within the measurement capability of NASA's gravimeter [8], so there is hope of detecting it.
One could also estimate the magnitude of a directly induced gravitoelectric field (Li/Torr eq. 3.7, p. 381), under the assumption that the vector points in the proper direction. It's maximum instantaneous value is given by

$$E_g^{ind} = 10^{-9}\, dA_0 / dt = (10^{-9}) * (6*10^{-5} \text{ Wb/m}) * (2\ \text{pi}*3.8*10^6) = 143 * 10^{-6} \text{ cm/s}^2 = 0.143 \text{ mGal} \qquad (5)$$

where the peak magnitude of the vector potential A = $6*10^{-5}$ Wb/m was estimated using QuickField in the harmonic magnetic mode, and the term dA_0 / dt is calculated using:

$$d\,(A_{peak} \sin(w\,t)) / dt = A_{peak} * w \cos(w\,t) \qquad (6)$$

whose maximum value is simply A_{peak} * w, and for which an operating frequency of 3.8 MHz was assumed. This still does not explain Podkletnov's result, but is much larger than the purely B_g acceleration. However, it is not clear what direction the E_g^{ind} vector would point in.

Conclusion

The wire size used in the coils seems to be adequate.
The levitation coils consist of 3 assemblies, each of which is made up of 2 coils connected with a U-shaped core, presumably of steel. This generates flux lines that travel horizonally under the disk, with some flux wrapping up and around the disk through the hole in the center.
Each coil could contain up to 310 turns of approximately 16 gauge wire, at 10 A maximum current. This results in a maximum magnetic flux density B of around 400 gauss at the bottom surface of the superconductor.
The 2 Tesla claim for the system in general does not seem to apply to the levitation coils. Even if one allows 850 gauss for each of 6 coils, right at their surfaces, the total field generated underneath the toroidal superconductor is only about 5100 gauss or 0.5 Tesla. And, this is only for static, not dynamic, magnetic fields. No estimate was made for eddy currents in the core, but intuitively it might be so high at the quoted frequency as to melt the device, or at least cause rapid boil-off of the cryogen due to high power dissipation. A dynamic analysis of this may be forthcoming from the author.
Estimates of the gravitoelectric and gravitomagnetic fields produced in such an arrangement are small, but large enough to be detected using a modern gravimeter. Of course, this estimate may very well be totally wrong, as the 10^{-9} coupling term in the Li/Torr paper may not apply to YBCO superconductors.
The author hopes that these calculations might enable others to reproduce Podkletnov's experiment more accurately. The author welcomes comments on the accuracy of this analysis.

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From a Relativistic Phenomenology of Anyons to a Model of Unification of Forces via the Spencer Theory of Lie Structures

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May 6, 2002

Abstract

Starting from a relativistic phenomenology of anyons in crystals, we discuss the concept of relativistic interaction and the need to unify electromagnetism and gravitation within the Spencer cohomology of Lie equations. Then, from the sophisticated non-linear Spencer complex of the Poincaré and conformal Lie pseudogroups, we build up a non-linear relative complex assigned to a gauge sequence for electromagnetic and gravitational potentials and fields. Then, using a conformally equivariant Lagrangian density, we deduce, first, the two first steps of its corresponding Janet complex and second, the dual relative linear complex. We conclude by giving suggestions for higher unification with the weak and strong interactions and interpretations of the Lagrangian density as a thermodynamical function and quantum wave-function.

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1. Introduction

In this paper we propose a model as well as suggestions for a unification of physical interactions. This is a model of electromagnetic and gravitational interactions well-founded on a phenomenological relativistic model of anyons in high-T_c superconductors (Rubin 1994). This unification has its roots, first in the Spencer cohomology of the conformal Lie pseudogroup which has abundantly been studied by J. Gasqui & H. Goldschmidt (Gasqui *et al.* 1984), and second, in the non-linear cohomology of Lie equations studied by H. Goldschmidt & D. Spencer (1976a, 1976b, 1978a, 1978b, 1981, see references therein). Meanwhile we only partially refer to some of its aspects to work out a relative non-linear cohomology explicitly associated with a model of unification. Such an approach was originally proposed by J.-F. Pommaret (1988, 1989, 1994) however, it appeared to us to be incomplete, indeed erroneous.

Thus, the purpose of the present paper is to discuss the Pommaret model and to suggest new developments based on the same assumption. Like Pommaret (1989), we think that the geometrical approach of the Maxwell theory has to be modified to be incorporated in a larger theory which explicitly includes gravitation through different equations describing the variations of potentials of gravitation. This result - or proposition - has not been obtained by Pommaret (Pommaret 1994, see conclusions page 456) who could not find any alternative descriptions and justifications neither for the Einstein theory, nor for the equations of fields of gravitation within the frame of the Spencer cohomology.

We conclude this paper a) by succinctly proposing a possible reinterpretation of the quantum wave-function as a classical thermodynamic function within the frame of the Misra-Prigogine-Courbage (MPC) ergodic theory of fields (Misra *et al.* 1979, Misra 1987), b) by suggesting ideas about a unification including the weak and strong interactions along a basic "à la Penrose" approach (Penrose *et al.* 1986).

Furthermore, this work is the result of informal reflexions about an increasing amount of contradictions and incoherences mainly concerning the concept of relativistic interaction, (that we find more and more serious) in the field of quantum physics as well as in classical physics. According to this observation, we first present our motives and a description of these contradictions in relation to F. Lurçat's (1964), J.-M. Lévy-Leblond's (1990) and J.-F. Pommaret's arguments (1989) in order to justify a development via the Spencer cohomology of Lie pseudogroups (Goldschmidt *et al.* 1976a, 1976b, 1978a, 1978b, 1981).

2. Goals and problems

2.1. The physics of crystals and a relativistic phenomenology of anyons

Our initial motivation shall be seen as extremely far from the problems with unifications. Actually, we were more concerned in a simple minor model of a relativistic phenomenology of creation of anyons, accurate for certain crystals (Rubin 1994). At the origin of this process of creation, we suggested the kinetico-magnetoelectrical effect as described by E. Asher (1973) and which has its roots in the former Minkowski works about the relations between tensors of polarization P and Faraday tensors F in a moving material of optical index $n \neq 1$.These relations are established by turning the following diagram into a commutative one:

$$\begin{array}{ccc} F' & \xrightarrow{\Lambda} & F \\ \Big\downarrow \chi' & & \Big\downarrow \chi \\ P' & \xrightarrow{\Lambda} & P \end{array}$$

where Λ is a Lorentz transformation, allowing us to shift from a frame R' to a frame R, and χ' and χ are respectively the tensors of susceptibility within those two frames, as well supposing P (or P') linearly depending on F (respectively F'). Resulting from this commutativity, the tensor χ linearly depends on χ' in general and also on a velocity 4-vector $\tilde{u}$ associated to Λ (i.e. the relative velocity 4-vector between R and R'). In assimilating R' to the moving crystal frame and R to the laboratory frame, then to an applied electromagnetic field F fixed in R, corresponds in R' a field of polarization P which varies in relation to $\tilde{u}$. This is the so-called kinetico-magnetoelectrical effect.

Parallel to this phenomenon, A. Janner & E. Asher studied the concept of relativistic point symmetry in polarized crystals (Janner *et al.* 1969, 1978). Such a symmetry is defined, on the one hand, by a given discret group G, sub-group of the so-called Shubnikov group $O(3)1'$ associated with the crystal, and on the other hand, as satisfying the following properties: to make this relativistic symmetry exist, there must be a $H(P)$ non-trivial group of Lorentz transformations depending on P, in which G is a normal sub-group, and that leaves the tensor of polarization P invariant. In other words, if $N(G)$ is the normalizer of G in the Lorentz group $O(1,3)$, and $K(P)$ the sub-group of $O(1,3)$ leaving P invariant, then $H(P)$ is the maximal sub-group such that:

$$\begin{cases} H(P) \subseteq K(P) \cap N(G) \\ H(P) \cap O(3)1' = G. \end{cases}$$

We can prove that $H(P)$ is about to exist only if a particular non-vanishing set V of velocity 4-vectors, invariant by action of G, is present and consequently compatible with a kinetico-magnetoelectrical effect (Asher 1973). Therefore, if there is an interaction between moving particles in the crystal and the polarization P, then the trajectories and P are obviously modified, and so is $H(P)$. In this process, only the group $N(G)$ is conserved so that the polarization and the trajectories are deducible during the time by the action of $N(G)$.

As we shall stipulate later on, the existence of an interaction will emerge due to a correlation between the position 3-vectors $\vec{r}$ of the charge carriers and a particular 3 - vector $\vec{w}$ ($\notin V$ in general) associated with P; $\vec{w}$ becoming then a function of $\vec{r}$. In order to allow a cyclotron-type motion which is implicit within the theory of anyons, the group $N(G)$ must contain the group $SO(2)$ and the latter must non-trivially act on all the groups $H(P)$ associated to G. Then, only 12 groups G are compatible with such a description

(Rubin 1993). In fact, throughout this development, we implicitly use a principle of equivalence similar to the one formulated in general relativity: one cannot distinguish a cyclotron - type motion in a constant polarization field from a uniform rectilinear motion in a field of polarization varying in time by action of the normalizer $N(G)$. The time evolution of $\vec{w}$ requiring the explicit knowledge of the gradient $\vec{\nabla}(\vec{w})$ of $\vec{w}$, it follows that $\vec{w}$ and $\vec{\nabla}(\vec{w})$ are respectively the analogues (not the equivalents) of the tetrads and of the Killing vector fields. From an other point of view, the interaction is considered to allow the extension of an invariance with respect to $H(P)$ to an invariance with respect to $N(G)$. The lack of interaction is then what breaks down the symmetry!

This type of reasoning concerns in fact a large amount of physical phenomena such as the spin-orbit interaction for instance. In this context, the cyclotron-type motion of electrons in anyonic states would be similar to the Thomas or Larmor precessions (see also the Coriolis or Einstein-Bass effects). More precisely, taking up again a computation, analogous to the Thomas precession one (Bacry 1967) (i.e. considering as a constant the scalar product of two tangent vectors being two parallel transports along the trajectory (Dieudonné 1971)), concerning a charge carrier with the velocity 4-vector $\tilde{u}$ in R, "polarized" by $\vec{w}(\vec{r})$ such as for example ($\tilde{v} = (0, \vec{v})_R$ constant and $\vec{v} \in V$):

$$\tilde{w} = (0, \vec{w})_R \equiv -P.\tilde{v} \ or \ {}^*P.\tilde{v},$$

where P depends on $\vec{r}$, one can prove from $\tilde{w}.\tilde{u} = cst.$ that (t being the laboratory frame time and ($\tilde{r} = (t, \vec{r})_R$):

$$\frac{d\tilde{u}}{dt} = (-e/m) F_{eff.}(\tilde{r}).\tilde{u}, \tag{1}$$

where m and e are respectively the mass and the electric charge of the carrier and $F_{eff.}(\tilde{r}) \equiv (\vec{E}_{eff.}(\tilde{r}), \vec{B}_{eff.}(\tilde{r}))$ is an effective Faraday tensor such that ($\gamma = (1 - \vec{w}^2)^{-\frac{1}{2}}$ and $\vec{j} = e\vec{u}$):

$$\begin{cases} \vec{B}_{eff.}(\tilde{r}) = (m/e^2)\left(\frac{\gamma}{1+\gamma}\right) \vec{w} \wedge \left[\vec{j}.\vec{\nabla}\right] \vec{w} \\ \vec{E}_{eff.}(\tilde{r}) = \vec{0}. \end{cases}$$

Clearly, $F_{eff.}$ is an element of the Lie algebra of the group $SO(2)$ included in $N(G)$ and with $\vec{B}_{eff.} \in V$. Therefore this $\vec{B}_{eff.}$ magnetic field or $\vec{v}$ (up to a constant) might be considered as the effective magnetic field of the flux-tube V generating the so-called Aharanov-Böhm effect at the origin of the statistical parameter in the anyons theory (Wilczek 1990). In this precession computation, from a more mathematical point of view, taking up the Lie groupoïds theory, we think that perhaps we shift from a source "description" (at $t = 0$) to a target one (at any $t \neq 0$). It is definitely an equivalence principle analogous to the one occuring in general relativity, as shown by J.-F. Pommaret (1989). Let us add that in general $\mathrm{div}(\vec{B}_{eff.}) \neq 0$ so that one gets a non-vanishing density of effective magnetic monopoles generated by the local variations (due to the interaction) of the polarization vector field $\vec{w}$ in the crystal. Thus an anyon would be an effective magnetic monopole associated with a charge carrier, namely a dyon. Moreover, because this effective Faraday tensor is no more a closed two-from, a non-vanishing Chern-Simon has to be taken into account in a Lagrangian description of anyons, from which non-vanishing spontaneous constant currents can occur.

2.2 Relativistic interaction in quantum mechanics

2.2.a. Polarization in quantum mechanics

The previous vector $\vec{B}_{eff.}$ (or $\vec{v} \in V$) has the same status as the spin. Like the latter, it is defined by a torsor of order 2. From that time on, the transition from a classical description to a quantum one means that one must give an account of the interaction between a free particle (constituting a first sub-system) and a torsor field of order 2 (constituting a second sub-system). The problem seems to be solved and in particular the spin appears to be a "minor" complication of the wave-function defined on the Minkowski space-time, i.e. on a "non-polarized" space. This has to be taken as a postulate, an erroneous one according to part of F. Lurçat's (1964) and J.-M. Lévy-Leblond's (1990) arguments.

In fact, it is not even the case according to classical Galilean mechanics. Considering a body at a given time, one needs to know 6 parameters to describe it: 3 for the position and 3 others for the orientation. The latter are forgotten during the transition from the "extended body to the punctual particle" according to the quantum description. This can only be justified providing that the energy of rotation is negligible compared to the energy of translation. This is the indicator of an inadequacy of the principle of correspondence from classical mechanics to quantum mechanics. But the transition from quantum to classical mechanics is equally problematic: reaching the limit $\hbar \to 0$, the spin vanishes. Finally, we must say that this correspondance does not exist any more in chromodynamics.

Therefore, the fact that the wave-function only depends on the position should rather be considered as a postulate (moreover, the fact is inexistant in classical mechanics). For instance, if we measure the electric and magnetic fields at a point in space-time with a system of coordinates defined by a given Lorentz transformation, we can deduce that the Faraday tensor is a function of the 4 parameters of the position and 6 others defining Λ. It explicitly occurs within the kinetico-magnetoelectric effect.

Refering now to the wave-equations and to the methods usually accepted to determine them, we then use a principle of invariance. First, we identify the appropriate space-time symmetries, that is the group of relativity of the theory (for example the Poincaré group). Then, according to Wigner's theory, we build the irreducible unitary representations (eventually projective) of the group to which correspond the elementary "kinetic" objects of the theory (i.e. the vector-valued wave-functions). Then again, we derive the infinitesimal generators of the group that we identify with physical and geometrical observables like the energy, the kinetic moment, etc...; the Lie algebra of the group and its "quantum" extensions defining the commutators. Finally, determining the invariants through the action of the group we obtain the other physical observables and their commutators.

Unfortunately, some ambiguities appear. For example, the generalization of the Dirac theory for spins higher than 1/2 gives different non-equivalent possible wave-equations.

Lastly, if we consider a theory of interacting fields, the particles associated with these fields can get out of their mass shell but not out of their spin shell! We then forget the spin again, which is impossible within a "(m,s)" theory. Therefore some of the aspects of the interaction and of the wave-equations - to be brief- can fully account for neither the free particles, nor the interacting particles!

In order to escape from these contradictions and to best describe the free particles, F. Lurçat proposed an approach "à la Wigner". In this way, he postulated that first the scalar complex wave-function of a free particle was defined on the "Poincaré space" of the Poincaré Lie group. Second, this wave-function is an eigenfunction of the two Casimirs of the Poincaré group. Thus, the wave-function ϕ is a function first, of a 4-vector position $\tilde{x}$, element of the dual Lie algebra of the group of translations and second, of a second order torsor F (like the Faraday torsor which is an element of the dual Lie algebra of the Lorentz group). Also in fact, the Poincaré Lie group on the "Poincaré space" is the action of a so-called Lie groupoïd on its associated Lie algebroïd, defined on the Minkowski space-time. Finally, if we want to describe the interaction, making these modifications and requiring a gauge invariance, the involution of the infinitesimal generators "deformed" by the gauge fields is no longer satisfied, nor are the relativistic invariance and the correspondence principle.

This breaking of the invariance can be seen with the Dirac equation. More exactly, the Dirac equation is not *equivariant*, but only covariant, meaning that this equation is not invariant under any conformal changes of coordinates, but only under a change of frame, i.e. a change of basis of the tangent Minkowski space. In that case, for instance, one of the spectacular manifestations is Klein's paradox of non-conservation of the current of probability during the scattering in a square potential (Itzykson *et al.* 1980). Still, the idea stays that ϕ is defined on a "larger" space-time than the Minkowski one, but for being a Kaluza-Klein type theory for example.

2.2.b. Concerning the contradictions of an approach "à la Wigner" and the Einstein-Cartan unification

Let us consider a complex wave-function ϕ depending on $\tilde{x}$ and F on which the Poincaré group projectively acts. Because, then, of the phase arbitrariness, the ten infinitesimal generators of the group are defined with ten arbitrary gauge potentials, so-called Poincaré potentials. In order to keep the Lie algebra structure, i.e. the involution of the deformed generators, the fields associated with these potentials must satisfy some constraint equations. The electromagnetic field associated with the translations of the group has especially to be vanishing, which is first absolutly contradictory with ϕ as a function of F. Second, that would mean that one cannot describe any interaction with a field F without a Poincaré symmetry breaking. Nevertheless this symmetry is necessary to keep the relativistic equivariance.

Moreover, ϕ is independent of the gauge potentials although ϕ should be parametrized by these functions refering to the formal theory of system of partial differential equations (PDE). In fact, according to the Kähler-Cartan theorem, the analytical solutions of an involutive system of PDE (so formally integrable) depend on certain constants of integration (Dieudonné 1971), but, contrary to the ODE (ordinary differential equations), they depend on arbitrary C^∞ functions only constrained to verify Cauchy initial data (see also Shih 1986, 1987, 1991). These functions should be identified with the gauge potentials and with their fields. Still, we can say that the incoherences are not over!

Let us assume the presence of a relativistic interaction, then there consequently exists, if we refer to the equivalence principle, a proper frame in which ϕ is stationnary. If τ is the "proper" time then $\partial_\tau \phi = 0$. Within the "laboratory" frame, we will get a different equation, moreover, there won't be any relativistic equivariance; a problem that is similarly encountered with either the Newton-Wigner position operator or the Dirac position operator. Indeed we will still be unable to write down this equation (!) for the reason that to shift to the Laboratory frame, one needs to know the classical motion of the particle, i.e. to know the equation that determines the evolution of the 4-vector speed $\tilde{u}$ identified with the basic time type 4-vector $\tilde{e}_0$ of the proper frame.

Also at this point, the equation should be established in a certain system of coordinates and from $\tilde{e}_0$ only, one should obtain the other basic vectors of space type $\tilde{e}_i$ (i=1,2,3) as well as their time evolutions. This equation should then be integrable in the Fröbenius sense. We think it is perhaps a matter of a generalisation of the Frênet moving frame method, as formulated by E. Cartan. Whereas we observe that by determining this moving frame from $\tilde{e}_0$ and $\dot{\tilde{e}}_0$, that the $\dot{\tilde{e}}_i$'s are defined from the $\tilde{e}_\mu$'s (μ=0,1,2,3) and from the third order time derivatives of $\tilde{e}_0$. Then, if $\dot{\tilde{e}}_0 \equiv F.\tilde{e}_0$, we need to know the time derivatives of F up to the second order. Therefore, in the laboratory frame, ϕ should depend on the derivatives of F, contrary to the initial assumption, unless these derivatives are themselves functions of F and $\tilde{x}$. Condition which, first, is not the case in the Maxwell theory, second would set down some constraints on the moving frame and consequently a "partial" equivariance; unless one completes it with other fields - like those associated for example with the space-time curvature - which would be related to the derivatives of F. Let us remark also that this kind of discussion seems to be very similar to the one encountered in the demonstration of the Cauchy-Kowalewska theorem when starting from a pfaffian system to a "normal system" of PDE's and considering the so-called "regular" tangent spaces and integrable manifolds (Dieudonné 1971).

On that subject, one can notice that the equation (1) can be rewritten in an orthonormal system of local coordinates ($\alpha, \beta, \gamma = 1, ..., n$; the Γ's being the Christoffel symbols):

$$\dot{u}^\alpha + \Gamma^\alpha_{\beta,\gamma} u^\beta u^\gamma = 0.$$

We recognize the equation of the geodesics associated to a Riemannian connexion with torsion. This would suggest a unification in reference to the Einstein-Cartan theory. If we then keep on with the assumption that one has to add to the electromagnetic field a gravitational field and that the derivatives of the fields are functions of the fields themselves (as with the Bianchi identities according to the non-abelian theory for example), that means we make the assumption of the existence of a differential sequence. In electromagnetism, it is a matter of the de Rham sequence but gravitation does not interfere. The sequence integrating the latter - and being the purpose of this paper - might be a certain generalizing complex like the Spencer one, following then a method proposed by J.-F. Pommaret (1994)but largely modified.

3. The Lie conformal pseudogroup associated to the unification model

First of all, let us assume that the group of relativity is not the Poincaré group anymore but the conformal Lie group (we know from Bateman and Cunningham studies (1910) that it is the group of invariance of the Maxwell equations). In particular, this involves that no changes occur shifting from a given frame to a uniformly accelerated relative one. From a historical point of view, that happened to be the starting point of the Weyl theory which was finally in contradiction with experimental data and for various other reasons presented, for instance by J.-F. Pommaret in the framework of the Janet and Spencer complexes (Pommaret 1989). Then, starting from this mathematical framework, J.-F. Pommaret considered in trying this unification, the linear Spencer complex defined from the system of finite Lie equations associated to the Lie pseudogroup of conformal isometries. Unfortunatly, the system of PDE proposed by J.-F. Pommaret is incomplete and its conditions of use are not really given. On the other hand, he claimed the Spencer complex of the conformal Lie pseudogroup would be the "unification complex" (Pommaret 1988), whereas we merely prove that it would rather be a relative complex deduced from an abelian extension (Godschmidt 1976a, 1976b, 1978a, 1978b, 1981), when reaching the conformal Lie pseudogroup starting from the Poincaré one. Before tackling these various complexes, we present and recall a few relations concerning the conformal Lie pseudogroup action on some tensors such as the metric and the Riemann and Weyl curvatures. Let us first call $\mathcal{M}$, the base space (or space-time), assumed to be of class C^∞, of dimension $n \geq 4$, connected, paracompact, without boundaries, oriented and endowed with a metric 2-form ω, symmetric, of class C^2 on $\mathcal{M}$ and non-degenerated. We also assume $\mathcal{M}$ to be conformally flat.

3.1. The conformal finite Lie equations

These equations are deduced from the conformal action on the metric. Let us consider $\hat{f} \in Diff^1_{loc.}(\mathcal{M})$ and any $\alpha \in C^0(\mathcal{M}, \mathbb{R})$, then if $\hat{f} \in \Gamma_{\widehat{G}}$ ($\Gamma_{\widehat{G}}$ being the pseudogroup of local conformal bidifferential maps on $\mathcal{M}$), $\hat{f}$ is a solution of the following system of PDE (other PDE must be satisfied to completly define $\Gamma_{\widehat{G}}$):

$$\left\{ \begin{array}{l} \hat{f}^*\omega = e^{2\alpha}\omega \\ \text{and with } \det(J(\hat{f})) \neq 0, \end{array} \right. \tag{2}$$

where $J(\hat{f})$ is the Jacobian of $\hat{f}$, and $\hat{f}^*$ is the pull-back of $\hat{f}$. We denote $\tilde{\omega}$ the metric on $\mathcal{M}$ such as:

$$\tilde{\omega} \overset{def.}{\equiv} e^{2\alpha}\omega,$$

and we agree to put a tilde on each tensor or geometrical "object" relative to or deduced from this metric $\tilde{\omega}$. Let us notice that the latter depends on a fixed given element $\hat{f}^* \in \Gamma_{\widehat{G}}$. Also, in order to properly recall the last point, we shall sometimes use an alternative notation such as:

$$\tilde{\omega} \stackrel{def.}{\equiv} {}^{\hat{f}}\omega.$$

This convention of notation will also be used on each geomerical object relative to this metric. Now, doing a first prolongation of the system (2), we deduce other second order PDE connecting the affine connexion 1-forms of Levi-Civita ∇ and $\widetilde{\nabla}$ respectively associated to ω and $\tilde{\omega}$. To obtain these PDE, we merely start from the following definition of $\widetilde{\nabla}$: let X, Y and Z be any vector fields in $C^1(T\mathcal{M})$, $\hat{f} \in Diff^2_{loc.}(\mathcal{M})$ and $\alpha \in C^1(\mathcal{M}, \mathbb{R})$, then by definition we have:

$$\begin{array}{rcl} \tilde{\omega}(\tilde{\nabla}_X Y, Z) & = & \frac{1}{2}\{\tilde{\omega}([X,Y],Z) + \tilde{\omega}([Z,X],Y) + \tilde{\omega}([Z,Y],Y) \\ & & +X.\tilde{\omega}(Y,Z) + Y.\tilde{\omega}(X,Z) - Z.\tilde{\omega}(X,Y)\}, \end{array} \tag{3}$$

from which we deduce with the relation (2) $\forall\, X, Y \in C^1(T\mathcal{M})$ and $\forall \hat{f} \in Diff^2_{loc.}(\mathcal{M})$,

$$\widetilde{\nabla}_X Y = \nabla_X Y + \mathbf{d}\alpha(X)Y + \mathbf{d}\alpha(Y)X - \omega(X,Y)\,{}_*\mathbf{d}\alpha, \tag{4}$$

where $\mathbf{d}$ is the exterior differential and ${}_*\mathbf{d}\alpha$ is the dual vector field of the 1-form $\mathbf{d}\alpha$ with respect to the metric ω, i.e. such as $\forall\, X \in T\mathcal{M}$

$$\omega(X, {}_*\mathbf{d}\alpha) = \mathbf{d}\alpha(X) =< \mathbf{d}\alpha | X > . \tag{5}$$

Let us also agree to denote in the sequel $\forall\, \tilde{x} \in \mathcal{M}$, $\forall\, \nu \in \bigwedge^r T^*\mathcal{M}$ and $\forall\, \xi_i \in T\mathcal{M}$ $(i = 1, ..., r)$:

$$\nu_{\tilde{x}}(\xi_{1,\tilde{x}}, ..., \xi_{r,\tilde{x}}) =< \nu(\tilde{x}) | \xi_{1,\tilde{x}} \otimes ... \otimes \xi_{r,\tilde{x}} > .$$

Prolonging again and using the definition of the Riemann tensor ρ associated to ω, i.e. $\forall\, X, Y \in C^2(T\mathcal{M})$

$$\rho(X,Y) = \nabla_X \nabla_Y - \nabla_Y \nabla_X - \nabla_{[X,Y]},$$

one obtains the following relation $\forall\, X, Y, Z \in C^2(T\mathcal{M})$, $\forall\, \alpha \in C^2(\mathcal{M}, \mathbb{R})$ and $\forall\, \hat{f} \in Diff^3_{loc.}(\mathcal{M})$,

$$\begin{array}{rcl} \tilde{\rho}(X,Y).Z & = & \rho(X,Y).Z + \omega(X,Z)\nabla_Y({}_*\mathbf{d}\alpha) - \omega(Y,Z)\nabla_X({}_*\mathbf{d}\alpha) \\ & & + \{\omega(\nabla_X({}_*\mathbf{d}\alpha), Z) + \omega(X,Z)\mathbf{d}\alpha({}_*\mathbf{d}\alpha)\}\, Y \\ & & - \{\omega(\nabla_Y({}_*\mathbf{d}\alpha), Z) + \omega(Y,Z)\mathbf{d}\alpha({}_*\mathbf{d}\alpha)\}\, X \\ & & + \{\mathbf{d}\alpha(X)\omega(Y,Z) - \mathbf{d}\alpha(Y)\omega(X,Z)\}\, {}_*\mathbf{d}\alpha \\ & & + \{\mathbf{d}\alpha(Y)X - \mathbf{d}\alpha(X)Y\}\, \mathbf{d}\alpha(Z) \end{array} \tag{6}$$

Assuming $\mathcal{M}$ to be comformally flat, the Weyl tensor τ associated with ω vanishes. Hence, the Riemann tensor ρ can be rewritten $\forall\, X, Y, Z, U \in C^2(T\mathcal{M})$ as:

$$\begin{array}{rcl} \omega(U, \rho(X,Y).Z) & = & \frac{1}{(n-2)}\, \{\omega(X,U)\sigma(Y,Z) - \omega(Y,U)\sigma(X,Z) \\ & & + \omega(Y,Z)\sigma(X,U) - \omega(X,Z)\sigma(Y,U)\}\,, \end{array} \tag{7}$$

where σ is the so-called Schouten tensor (Gasqui /it et al. 1984) $\forall\, X, Y \in C^2(T\mathcal{M})$,

$$\sigma(X,Y) = \rho_{ic}(X,Y) - \frac{\rho_s}{2(n-1)}\omega(X,Y), \tag{8}$$

where ρ_{ic} is the Ricci tensor and ρ_s is the Riemann scalar curvature. Thus, we might consider the relation (7) as the existence of a short exact sequence "symbolically" written as "$0 \to \sigma \to \rho \to \tau \to 0$" and perhaps related to a sequence of cohomology spaces of symbols (Gasqui *et al.* 1984, Pommaret 1994). Consequently, the system of PDE (6) can be rewritten as a first order system of PDE concerning σ. To do this, we first define two suitable trace operators, used in the sequel to obtain the $\tilde{\rho}_{ic}$ and $\tilde{\rho}_s$ tensors and finally the $\tilde{\sigma}$ tensor. Let us denote Tr^1 the trace operator defined such that for any vector bundle E over $\mathcal{M}$ we have:

$$Tr^1 : T\mathcal{M} \otimes T^*\mathcal{M} \otimes E \longrightarrow E,$$

with

$$Tr^1(X \otimes \alpha \otimes \mu) = \alpha(X)\mu$$

for any $X \in T\mathcal{M}$, $\alpha \in T^*\mathcal{M}$ and $\mu \in E$. Then, the second trace operator is the natural trace Tr_ω associated to ω and defined by:

$$Tr_\omega : \overset{2}{\otimes} T^*\mathcal{M} \longrightarrow \mathbb{R},$$

such that

$$Tr_\omega(u \otimes v) = v(_*u).$$

Finally, with $Tr^1\tilde{\rho} = \tilde{\rho}_{ic}$ and $Tr_\omega\tilde{\rho}_{ic} = \tilde{\rho}_s$, we deduce first from the relations (6) and (8) $\forall \hat{f} \in Diff^3_{loc.}(\mathcal{M})$, $\forall X, Y \in C^2(T\mathcal{M})$ and $\forall \alpha \in C^2(\mathcal{M}, \mathbb{R})$,

$$\begin{aligned} \tilde{\sigma}(X,Y) \;&=\; \sigma(X,Y) + (n-2)\big(\mathbf{d}\alpha(X)\mathbf{d}\alpha(Y) - \omega(\nabla_X(_*\mathbf{d}\alpha), Y) \\ &\quad -\tfrac{1}{2}\omega(X,Y)\mathbf{d}\alpha(_*\mathbf{d}\alpha)\big)\,. \end{aligned} \tag{9}$$

In fact this expression can be symmetrized. Indeed, from the following property satisfied by ∇:

$$\omega(\nabla_X(_*\mathbf{d}\alpha), Y) + \omega(_*\mathbf{d}\alpha, \nabla_X Y) = X.\,\omega(_*\mathbf{d}\alpha, Y),$$

and the definition of $_*\mathbf{d}\alpha$, one obtains:

$$\omega(\nabla_X(_*\mathbf{d}\alpha), Y) = X.\,\mathbf{d}\alpha(Y) - \mathbf{d}\alpha(\nabla_X Y).$$

But, from the torsion free property of ∇ and from the relation

$$\mathbf{d}\alpha([X,Y]) = X.\,\mathbf{d}\alpha(Y) - Y.\,\mathbf{d}\alpha(X),$$

one deduces:

$$\omega(\nabla_X(_*\mathbf{d}\alpha), Y) = Y.\mathbf{d}\alpha(X) - \mathbf{d}\alpha(\nabla_Y X).$$

Now, $\forall\, \alpha \in C^2(\mathcal{M}, \mathbb{R})$, $\forall\, X, Y \in C^1(T\mathcal{M})$, defining $\mu \in C^0(S_2T^*\mathcal{M})$ by:

$$\mu(X,Y) = \frac{1}{2}\left[X.\,\mathbf{d}\alpha(Y) + Y.\,\mathbf{d}\alpha(X)\right], \tag{10}$$

one has the relation:

$$\omega(\nabla_X({}_*\mathbf{d}\alpha), Y) = \mu(X,Y) - \frac{1}{2}\mathbf{d}\alpha(\nabla_X Y + \nabla_Y X).$$

Then, we can rewrite the first order PDE (9), $\forall\, \hat{f} \in Diff^3_{loc.}(\mathcal{M})$, $\forall\, X, Y \in C^2(T\mathcal{M})$ and $\forall\, \alpha \in C^2(\mathcal{M}, \mathbb{R})$ as:

$$\begin{array}{rcl}\tilde{\sigma}(X,Y) & = & \sigma(X,Y) + (n-2)\,(\mathbf{d}\alpha(X)\mathbf{d}\alpha(Y) \\ & & -\mu(X,Y) + \frac{1}{2}\mathbf{d}\alpha(\nabla_X Y + \nabla_Y X) \\ & & -\frac{1}{2}\omega(X,Y)\mathbf{d}\alpha({}_*\mathbf{d}\alpha)\Big).\end{array} \tag{11}$$

It is worthy of note that if $\rho_s = c_0$ ($c_0 \in \mathbb{R}$), then the Schouten tensor σ satisfies the relation:

$$\sigma = c_0\frac{(n-2)}{2}\omega. \tag{12}$$

and only in this case, the equation (11) must become the equation 2 ans so it desappears. Then, considering the system (2), the system (11) reduces to a second order system of PDE such as $\forall\, \alpha \in C^2(\mathcal{M}, \mathbb{R})$ and $\forall\, X, Y \in C^1(T\mathcal{M})$ we have:

$$\begin{array}{rcl}\mu(X,Y) & = & \frac{1}{2}\left\{\left[c_0\left(1-e^{2\alpha}\right) - \mathbf{d}\alpha({}_*\mathbf{d}\alpha)\right]\omega(X,Y) + \mathbf{d}\alpha\left(\nabla_X Y + \nabla_Y X\right)\right\} \\ & & -\mathbf{d}\alpha(X)\mathbf{d}\alpha(Y).\end{array} \tag{13}$$

We also have the following PDE deduced from (4), $\forall\, X \in C^1(T\mathcal{M})$ and $\forall\, \hat{f} \in Diff^2_{loc.}(\mathcal{M})$:

$$Tr^1(\widetilde{\nabla}_X) = Tr^1(\nabla_X) + n\,\mathbf{d}\alpha(X). \tag{14}$$

Thus, we have a serie of PDE deduced from (2), in particular made of the systems of PDE (2), (11) and (14). But there are alternative versions of these PDE in which the function $\alpha \in C^2(\mathcal{M}, \mathbb{R})$ doesn't appear. These latters are the following: from the system (2), one deduces, $\forall\, \hat{f} \in Diff^1_{loc.}(\mathcal{M})$:

$$\left\{\begin{array}{l}\hat{f}^*\hat{\omega} = \hat{\omega} \\ \text{and with } \det(J(\hat{f})) \neq 0,\end{array}\right. \tag{15}$$

where $\hat{\omega} = \omega/|\det(\omega)|^{1/n}$. Then by prolongation, with $\widehat{\nabla}$ and $\hat{\rho}$ being respectively the connexion of Levi-Civita and the Riemann curvature tensor associated to $\hat{\omega}$, one obtains $\forall\, \hat{f} \in Diff^3_{loc.}(\mathcal{M})$:

$$^{\hat{f}}\widehat{\nabla} = \widehat{\nabla} \tag{16}$$

and

$$^{\hat{f}}\hat{\rho} = \hat{\rho}. \tag{17}$$

In the latter system (17) of PDE (first order), it has to be noted that $\hat{\rho} = \tau$, i.e. $\hat{\rho}$ is the Weyl curvature tensor associated to the metric ω. Furthermore, with the assumption that the conformal structure is flat, one has $\hat{\rho} = 0$ and $\hat{\sigma} = 0$. But in general, it is noteworthy to add that if $\tau = 0$ then obviously σ doesn't vanish. Then, the conformal Lie pseudogroup $\Gamma_{\widehat{G}}$ is the set of functions $\hat{f} \in Diff^3_{loc.}(\mathcal{M})$ satisfying the following involutive system of PDE:

$$\begin{cases} \hat{f}^*\hat{\omega} = \hat{\omega} \qquad \text{and with} \qquad \det(J(\hat{f})) \neq 0 \\ ^{\hat{f}}\widehat{\nabla} = \widehat{\nabla}, \end{cases} \tag{18}$$

completed with a third system of PDE of order 3 defined $\forall\, X, Y \in C^2(T\mathcal{M})$ by:

$$^{\hat{f}}\widehat{\nabla}_X {}^{\hat{f}}\widehat{\nabla}_Y = \widehat{\nabla}_X \widehat{\nabla}_Y. \tag{19}$$

This system is formally integrable if and only if $\tau = 0$ (from the Weyl theorem) and involutive because the corresponding symbol $\widehat{M}_3$ vanishes. From a terminological point of view, one shall say that the system (18)-(19) is the "Lie form" of the system made of the PDE (2), (11) and (14) to which one adds the third order system deduced from the expression of $^{\hat{f}}\widehat{\nabla}_X {}^{\hat{f}}\widehat{\nabla}_Y$ with respect to $\nabla_X \nabla_Y$ and $\alpha \in C^3(\mathcal{M}, \mathbb{R})$. We shall call this latter system equivalent to the system (18)-(19), the "deformed" or "extended" system. It is remarkable that the deformed system brings out a supplementary system in comparison with its Lie form (18)-(19). It is about the system (11). If we consider the second order sub-system deduced from the system (18)-(19), we notice it is still formally integrable (again because of the Weyl theorem) but it is no longer involutive because the symbol $\widehat{M}_2$ of (18)-(19) is only 2-acyclic.

3.2. The conformal Lie groupoïd

Before defining this groupoïd, we need to recall some definitions concerning the sheafs of the k-jet fiber bundles (Kumpera *et al.* 1972). First of all, we denote $J_k(\mathcal{M})$ the affine fiber bundle of the k-jets of local $C^\infty(\mathcal{M}, \mathcal{M})$ functions on $\mathcal{M}$, $\theta_{\mathcal{M}}$ (or simply θ) the sheaf of local rings of germs of continuous functions on $\mathcal{M}$ with values in $\mathbb{R}$, and J_k the affine fiber bundle of the k-jets of local functions in $C^\infty(\mathcal{M}, \mathbb{R})$. Then in what follows, we agree to underline all the names used for the sheafs of germs of local continuous sections associated with the various fiber bundles. Now, if ϵ is a sheaf of θ-modules on $\mathcal{M}$, we conventionally define the sheaf $\underline{J_k(\epsilon)}$ as:

$$\underline{J_k(\epsilon)} \equiv \underline{J_k} \otimes_\theta \epsilon.$$

Then, we have the injective sheafs map:

$$
\begin{array}{rccc}
j_k : & \underline{C^\infty(\mathcal{M})} & \longrightarrow & \underline{J_k(\mathcal{M})} \\
& [m \to f(m)]_x & \longrightarrow & [m \to j_k(f)(m)]_x \equiv j_k([f])_x,
\end{array}
$$

where $j_k(f)(m)$ is the set of germs at m of the derivatives of f up to order k, and $[\ ]_x$ obviously being the equivalence classes of local sections at $x \in \mathcal{M}$. Let us also denote $\underline{Aut(\mathcal{M})}$ the sheaf of germs of functions $f \in Diff^\infty_{loc.}(\mathcal{M})$. The source map such as:

$$
\begin{array}{rccc}
\alpha_k : & J_k(\mathcal{M}) & \longrightarrow & \mathcal{M} \\
& j_k(f)(x) & \longrightarrow & x,
\end{array}
$$

and the target map:

$$
\begin{array}{rccc}
\beta_k : & J_k(\mathcal{M}) & \longrightarrow & \mathcal{M} \\
& j_k(f)(x) & \longrightarrow & f(x),
\end{array}
$$

are submersions on $\mathcal{M}$. One defines the composition on $J_k(\mathcal{M})$ by:

$$
J_k(g)(y) \,.\, J_k(f)(x) = J_k(g \circ f)(x),
$$

with $y = f(x)$. The units in $\underline{J_k(\mathcal{M})}$ are the elements $j_k([id])_x$ and they can be identified with the points $x \in \mathcal{M}$. Then, let $\Pi_k(\mathcal{M})$ be the Lie groupoïd of invertible elements of $J_k(\mathcal{M})$. The elements of $\Pi_k(\mathcal{M})$ are the k-jets of the functions $f \in Diff^\infty_{loc.}$. $\underline{J_k(\mathcal{M})}$ (resp.$\underline{\Pi_k(\mathcal{M})}$) is also the sheaf of germs of local continuous sections f_k of α_k (resp. $\alpha_k/\Pi_k(\mathcal{M})$). The sheaf map j_k can be also restricted to the sheaf map:

$$
j_k : \underline{Aut(\mathcal{M})} \longrightarrow \underline{\Pi_k(\mathcal{M})}.
$$

An element $[f_k] \in \underline{\Pi_k(\mathcal{M})}$ shall be called "admissible" if $f = \beta_k \circ f_k \in Aut(\mathcal{M})$ (i.e. $\det([j_1(f)]) \neq 0$). The admissible elements are the germs of continuous sections f_k of $\alpha_k : \Pi_k(\mathcal{M}) \to \mathcal{M}$ such as $\beta_k \circ f_k \in Diff^\infty_{loc.}(\mathcal{M})$. We denote $\Gamma_k(\mathcal{M})$ the sub-sheaf of admissible elements of $\underline{\Pi_k(\mathcal{M})}$. Then, we can define the sheaf epimorphism of groupoïds:

$$
j_k : \underline{Aut(\mathcal{M})} \longrightarrow \Gamma_k(\mathcal{M}).
$$

Finally, we define the source map a_k and the target map b_k in $\underline{J_k(\mathcal{M})}$ by:

$$
\begin{array}{rccc}
a_k : & \underline{J_k(\mathcal{M})} & \longrightarrow & \mathcal{M} \\
& [\sigma_k]_x & \longrightarrow & x,
\end{array}
$$

$$
\begin{array}{rccc}
b_k : & \underline{J_k(\mathcal{M})} & \longrightarrow & \mathcal{M} \\
& [\sigma_k]_x & \longrightarrow & \beta_k \circ \sigma_k(x),
\end{array}
$$

and the canonical projection Π^p_q $(p \geq q)$ by:

$$
\begin{array}{rccc}
\Pi^p_q : & \underline{J_p(\mathcal{M})} & \longrightarrow & \underline{J_q(\mathcal{M})} \\
& [f_p]_x & \longrightarrow & [f_q]_x.
\end{array}
$$

Thus, at the sheafs level, the non-linear finite Lie groupoïd $\widehat{\mathcal{R}}_3$ of the conformal pseudogroup $\Gamma_{\widehat{G}}$ is the set of germs of continuous sections in $\Gamma_3(\mathcal{M})$ satisfying the algebraic equations over each point $x \in \mathcal{M}$, obtained by substituting the germs $[\hat{f}_3]_x \in \Gamma_3(\mathcal{M})$ for the derivatives of $\hat{f}$ up to order three in the system of PDE (18)-(19). In other terms, we substitute $[\hat{f}_3]$ for $j_3([\hat{f}])$. More precisely, one factorizes each differential operator of the system (18)-(19) with the operators j_k $(k = 1, 2, 3)$. Then, one defines the morphisms:

$$\left\{\begin{array}{rrcl} M(\hat{\omega}): & j_1(\mathcal{M}) & \longrightarrow & S_2T^*\mathcal{M} \\ L(j_1(\hat{\omega})): & j_2(\mathcal{M}) & \longrightarrow & T\mathcal{M}\otimes T^*\mathcal{M}\otimes J_1^*(T\mathcal{M}) \\ K(j_2(\hat{\omega})): & j_3(\mathcal{M}) & \longrightarrow & T\mathcal{M}\otimes T^*\mathcal{M}\otimes J_1^*(T\mathcal{M})\otimes J_2^*(T\mathcal{M}) \end{array}\right.$$

by the respective following relations:

$$\left\{\begin{array}{rcl} \hat{f}^*\hat{\omega} & = & M(\hat{\omega})\circ j_1(\hat{f}) \\ {}^{\hat{f}}\widehat{\nabla} & = & L(j_1(\hat{\omega}))\circ j_2(\hat{f}) \\ {}^{\hat{f}}\widehat{\nabla}{}^{\hat{f}}\widehat{\nabla} & = & K(j_2(\hat{\omega}))\circ j_3(\hat{f}), \end{array}\right.$$

and consequently $\widehat{\mathcal{R}}_3$ can be rewritten as the system of PDE made of the two systems of PDE $\widehat{\mathcal{R}}_2$:

$$\left\{\begin{array}{lcl} {}^{[\hat{f}_1]}\hat{\omega} & \overset{def.}{\equiv} & M(\hat{\omega})([\hat{f}_1]) = \hat{\omega} \ \text{with} \ \det([\hat{f}_1]) \neq 0 \ \text{and} \ \det([j_1(\hat{f})]) \neq 0 \\ {}^{[\hat{f}_2]}\widehat{\nabla} & \overset{def.}{\equiv} & L(j_1(\hat{\omega}))([\hat{f}_2]) = \widehat{\nabla}, \end{array}\right. \tag{20}$$

completed with the third system:

$${}^{[\hat{f}_3]}(\widehat{\nabla}\widehat{\nabla}) \overset{def.}{\equiv} K(j_2(\hat{\omega}))([\hat{f}_3]) = \widehat{\nabla}\widehat{\nabla}. \tag{21}$$

$\Gamma_{\widehat{G}}$ is then the set of germs $[\hat{f}] \in Aut(\mathcal{M})$ such as $j_3([\hat{f}]) \in \widehat{\mathcal{R}}_3$. Now since $\widehat{M}_3 = 0$, one also has the equivalence $\widehat{\mathcal{R}}_3 \simeq \widehat{\mathcal{R}}_2$ and in order to work out the sophisticated non-linear Spencer complex of $\widehat{\mathcal{R}}_3$, it is sufficient, as we shall see later, to obtain it for $\widehat{\mathcal{R}}_2$. That is because the exactness of this complex of length two, only needs the symbol of the corresponding Lie groupoïd to be 2-acyclic. It is precisely the case for $\widehat{M}_2$. Thus, the discussion in what follows will concern exclusively $\widehat{\mathcal{R}}_2$ defined by the "deformed" or "extended" system: $\forall\, X, Y \in C^2(T\mathcal{M})$ and $\forall\, [\alpha_2] = ([\alpha], [\beta], [\mu]) \in \underline{J_2}$,

$$\widehat{\mathcal{R}}_2 : \left\{\begin{array}{rcl} {}^{[\hat{f}_1]}\omega & = & e^{2[\alpha]}\omega \ \text{with} \ \det([\hat{f}_1]) \neq 0 \ \text{and} \ \det([j_1(\hat{f})]) \neq 0 \\ {}^{[\hat{f}_2]}\nabla_X Y & = & \nabla_X Y + [\beta](X)Y + [\beta](Y)X - \omega(X,Y)\,{}_*[\beta] \\ {}^{[\hat{f}_1]}\sigma(X,Y) & = & \sigma(X,Y) + (n-2)\Big([\beta](X)[\beta](Y) - \frac{1}{2}\omega(X,Y)[\beta]({}_*[\beta]) \\ & & \quad - [\mu](X,Y) + \frac{1}{2}[\beta](\nabla_X Y + \nabla_Y X)\Big). \end{array}\right. \tag{22}$$

Let us precise again that the equation (11) makes sense, and in the formula (22) the last equation must be considered. Indeed, in case of a conformally non-flat background metric ω, the Lie form of $\widehat{\mathcal{R}}_2$ given by the set of equations (15), (16) and (17), is equivalent to the set of equations made of the two first equations in formula (22) together with the equation (6). Then setting $\widehat{\rho} = \tau = 0$ (i.e. a conformally flat metric ω), doesn't change this equivalence, but in that case the equation (6) becomes equivalent to equation (11), and thus the "extended form" of $\widehat{\mathcal{R}_2}$ is the formula (22) and we have one equation more than in the Lie form case. The latter point is rather important to make the difference between the two forms. Obviously the groupoïd $\mathcal{R}_2 \subset \widehat{\mathcal{R}_2}$ of the Poincaré pseudogroup corresponds to the case for which $[\alpha_2] = 0$. The symbol M_2 of $\mathcal{R}_2$ vanishes and so is involutive, and $\mathcal{R}_2$ is not formally integrable unless ρ_s is a constant. The present suggested model is associated to a particular split exact short sequence of groupoïds (not of Lie groupoïds because of $\not{\mathcal{R}}_2$):

$$1 \longrightarrow \mathcal{R}_2 \longrightarrow \widehat{\mathcal{R}_2} \longrightarrow \not{\mathcal{R}}_2 \longrightarrow 1,$$

and in order to have a relative exact non-linear (even so fractional!) complex associated to $\not{\mathcal{R}}_2$, the complex associated to $\mathcal{R}_2$ would also have to be exact. This is possible only if $\mathcal{R}_2$ is formally integrable and consequently involutive ($M_2 = 0$). Setting these conditions it follows that the relation (12) must be satisfied at the sheaf level. Then from relation (12) and (22), one deduces $\not{\mathcal{R}}_2$ is the set of elements $[\alpha_2] \in \underline{J_2}$ such as $\forall\, X, Y \in T\mathcal{M}$ and $\forall\, c_0 \in \mathbb{R}$:

$$\not{\mathcal{R}}_2 : \qquad \left\{ \begin{array}{rcl} [\mu](X,Y) &=& \frac{1}{2}\Big\{\Big[c_0\left(1-e^{2[\alpha]}\right) - [\beta](_*[\beta])\Big]\,\omega(X,Y) \\ && +[\beta]\left(\nabla_X Y + \nabla_Y X\right)\Big\} - [\beta](X)[\beta](Y), \end{array}\right. \tag{23}$$

and only with these conditions does $\widehat{\mathcal{R}_2}$ reduce indeed to the system chosen by J.-F. Pommaret. Thus, $[\mu]$ is completly defined from $[\alpha]$ and $[\beta]$ so that the symbol $\not{M}_2$ of $\not{\mathcal{R}}_2$ obviously vanishes. Hence, $\not{\mathcal{R}}_2$ is involutive and one has the equivalence:

$$\not{\mathcal{R}}_2 \simeq \not{\mathcal{R}}_1 = \underline{J_1},$$

deduced from the embedding of $\underline{J_1}$ in $\underline{J_2}$ defined by the system (23). Consequently, one has to work out the complex associated to $\not{\mathcal{R}}_1$ such that:

$$1 \longrightarrow \mathcal{R}_2 \longrightarrow \widehat{\mathcal{R}_2} \xrightarrow{\phi_0} \not{\mathcal{R}}_1 \longrightarrow 1.$$

The sequences above are sequences of groupïds but not of Lie groupoïds. That $\not{\mathcal{R}}_2 \equiv \underline{J_1}$ is a groupoïd can be seen directly from the definition of ϕ_0 as we shall see in the sequel or first by considering locally, above each pair of open subsets $U \times V \subset \mathcal{M} \times \mathcal{M}$ the corresponding associated trivial local groupoïds $U \times G_{U\times V} \ \times \ V \simeq \ \mathcal{R}_{2/U\times V}$ (and with analogous expressions for the other $\mathcal{R}$'s). Then we obtain a corresponding sequence of algebraic groups on a finite projective free module for the G's. Since they are algebraic they are splittable and the sequence is split exact. Therefore we can find a splitting of groups (such as an Iwasawa decomposition for instance), by a good choice of back-connection. Then $\not{\mathcal{R}}_{1/U\times V}$ can be canonically injected in $\widehat{\mathcal{R}_{2/U\times V}}$ so that it acquires locally an algebraic group structure. Then, by gluing over all pairs of open subsets $U \times V$, we deduce the sequence of groupoïds. Let us add from the definition of $\widehat{\mathcal{R}_2}$ that $\not{\mathcal{R}}_1$ is a natural bundle associated to $\widehat{\mathcal{R}_2}$. From a physical point of view, it is important to notice that μ may be considered as an Abraham-Eötvos type tensor, leading to a first physical interpretation (up to a constant for units) of β as the acceleration 4-vector of gravity. On the other hand, completly in agreement with J.-F. Pommaret, α being associated with the dilatations it can be considered as a relative Thomson type temperature (again up to a constant for units):

$$\alpha = \ln(T_0/T), \tag{24}$$

where T_0 is a constant temperature of reference associated with the base space-time $\mathcal{M}$. Then, one can easily define the epimorphism ϕ_0 by the relations $\forall\,[\hat{f}_2] \in \widehat{\mathcal{R}}_2$:

$$\phi_0([\hat{f}_2]) = \left\{ \begin{array}{lcl} [\alpha] & = & \frac{1}{n}\ln|\det([\hat{f}_1])| \\ [\beta] & = & \frac{1}{n}Tr_\omega\left({}^{[\hat{f}_2]}\nabla - \nabla\right). \end{array} \right. \tag{25}$$

Thus, we get a first diagram:

$$\begin{tikzcd}
 & 1 \arrow[d] & 1 \arrow[d] \\
1 \arrow[r] & \Gamma_G \arrow[r, "j_2"] \arrow[d] & \mathcal{R}_2 \arrow[d] \\
1 \arrow[r] & \Gamma_{\widehat{G}} \arrow[r, "j_2"] \arrow[d] & \widehat{\mathcal{R}}_2 \arrow[d, "\phi_0"] \\
1 \arrow[r] & \theta \arrow[r, "j_1"] & \underline{J_1} \arrow[d] \\
 & & 0
\end{tikzcd} \tag{26}$$

Before presenting the various non-linear Spencer complexes we shall recall briefly certain definitions and results of this theory. The Spencer Theory presentation we give below is rather minimal since we think that it is impossible to describe it perfectly in few pages. It is especially a matter of indicating the notations chosen in the text and we do not claim to make a full and complete description. Moreover, this theory is presented and taken up historically with the "diagonal method" of Grothendieck (Kumpera *et al.* 1972), and the results and definitions we give don't mention it. In this method, two copies of the base space $\mathcal{M}$ are used. The first one $\mathcal{M}_1$ (the horizontal component) is attributed to the set of "points" on which the Taylor coefficients of particular Taylor series are defined, and the second $\mathcal{M}_2$ (the vertical component), to points on which these previous series are evaluated. The independence of this evaluation with respect to the points chosen in $\mathcal{M}_1$ allow to deduce the first Spencer differential operator (linear or non-linear) as an exterior differential operator on the horizontal component. Then the second Spencer differential operator and a particular set of derivations are deduced from the equivariance of the first Spencer differential operator with respect to a particular groupoïd action. Thus, the Spencer cohomology can be seen mainly as an equivariant cohomology on graded sheafs of the diagonal of $\mathcal{M}_1 \times \mathcal{M}_2$. Actually, we give the results and formulas after the vertical (diagonal isomorphism) projection on the vertical component of various diagonal graded sheafs defined on $\mathcal{M}_1 \times \mathcal{M}_2$ and following in parts a formulation given by J.-F. Pommaret especially when concerning the definition of the differential bracket. The other definitions are merely the vertical "translations" of the definitions given by Kumpera and Spencer applying the so-called "ϵ" isomorphism on the diagonal sheafs.

3.3. The first non-linear Spencer differential operators

First, we recall that $\underline{\Lambda\, T^*\mathcal{M}} \otimes_\theta \underline{J_k(E)}$, where E is a vector bundle, has a natural left $\underline{\Lambda\, T^*\mathcal{M}}$-module structure.

Definition 1 *a) The linear Spencer operator D is the unique differential operator ($\mathbb{R}$-linear sheaf map; $k, s \geq 0$)*

$$D : \underline{\Lambda\, T^*\mathcal{M}} \otimes_\theta \underline{J_{k+1}(E)} \longrightarrow \underline{\Lambda\, T^*\mathcal{M}} \otimes_\theta \underline{J_k(E)},$$

satisfying the three following conditions:

1. $D \circ j_{k+1} = 0$,
2. $\forall \tau_{k+1} \in \underline{\Lambda\, T^*\mathcal{M}} \otimes_\theta \underline{J_{k+1}(E)}, \qquad D(\omega \wedge \tau_{k+1}) = \mathbf{d}\omega \wedge \tau_k + (-)^{d^0\omega} \omega \wedge D\tau_k$
   where $\omega \in \underline{\Lambda\, T^*\mathcal{M}}$ is any homogeneous differential form and $\mathbf{d}$ being the exterior differential,
3. *D restricted to $J_{k+1}(E)$ satisfies:*

$$\epsilon_1 \circ D = j_1 \circ \Pi_k^{k+1} - id_{J_{k+1}(E)},$$

where ϵ_1 is the monomorphism defined by the short exact sequence:

$$0 \longrightarrow T^*\mathcal{M} \otimes J_k(E) \xrightarrow{\epsilon_1} J_1(J_k(E)) \xrightarrow{\Pi_0^1} J_k(E) \longrightarrow 0.$$

b) The restriction of $(-D)$ to the symbol $\underline{\Lambda\, T^*\mathcal{M}} \otimes_\theta \underline{S_k T^*\mathcal{M}} \otimes_\theta \underline{E}$ defines the $\underline{\Lambda\, T^*\mathcal{M}}$-linear Spencer map $\underline{\delta}$ such that

$$\underline{\delta}(\omega \wedge \tau_k) = (-)^{d^0\omega} \omega \wedge \underline{\delta}(\tau_k),$$

with ω and τ_k as in a)-3..

■

Definition 2 *We define the r-th Spencer sheaf* ($r \geq 1$) *of* $J_k(E)$, *the quotient sheaf*

$$\mathcal{C}_k^r(E) = \underline{\Lambda^r\, T^*\mathcal{M}} \otimes_\theta \underline{J_k(E)} / \zeta_k \circ \underline{\delta}(\underline{\Lambda^{r-1}\, T^*\mathcal{M}} \otimes_\theta \underline{S_{k+1} T^*\mathcal{M}} \otimes_\theta \underline{E}),$$

where ζ_k *is the monomorphism defined by the short exact sequence:*

$$0 \longrightarrow S_k T^*\mathcal{M} \otimes E \xrightarrow{\zeta_k} J_k(E) \xrightarrow{\Pi_{k-1}^k} J_{k-1}(E) \longrightarrow 0.$$

■

Let us add that $\mathcal{C}_k^r(E)$ has a module structure on the θ-algebra $\underline{J_k}$ and we set $\mathcal{C}_k^r(E) = 0$ for $r > n$ and $\mathcal{C}_k^0(E) = \underline{J_k(E)}$.

Definition 3 *The operator* D *can be factorized with a right* θ*-linear operator* D' *on* $\mathcal{C}_k^r(E)$:

$$D' : \mathcal{C}_k^r(E) \longrightarrow \mathcal{C}_k^{r+1}(E).$$

■

Contrary to the operator D, there is no loss of order on k. More precisely, D' is such that the following diagram of split exact sequences is commutative:

$$\begin{tikzcd}
0 \arrow[d] & 0 \arrow[d] \\
\underline{S_{k+1}T^*\mathcal{M}} \otimes_\theta \underline{E} \arrow[r, "(-\delta)"] \arrow[d, "\zeta_{k+1}"] & \underline{T^*\mathcal{M}} \otimes_\theta \underline{S_k T^*\mathcal{M}} \otimes_\theta \underline{E} \arrow[d, "id \otimes \zeta_k"] \\
\underline{J_{k+1}(E)} \arrow[r, "D"] \arrow[d, "\Pi_k^{k+1}"] & \underline{T^*\mathcal{M}} \otimes_\theta \underline{J_k(E)} \arrow[d, "\rho_k^{k+1}"] \\
\underline{J_k(E)} \arrow[r, "D'"] \arrow[d] & \mathcal{C}_k^1(E) \arrow[d] \\
0 & 0
\end{tikzcd}$$

It is to be noted that the sequences being split, then D' is built up from a connexion

$$c_{k+1}^k : \underline{J_k(E)} \longrightarrow \underline{J_{k+1}(E)},$$

such that by definition

$$\Pi_k^{k+1} \circ c_{k+1}^k = id_k.$$

But quotienting, then by definition, D' is independent of the choice of connexion c^k_{k+1}. Hence, whatever is c^k_{k+1}, one has

$$D' = \rho^{k+1}_k \circ D \circ c^k_{k+1}.$$

Finally, for $r \geq 1$, these definitions can be extended to the tangent bundle R_k of $\mathcal{R}_k$ instead of $J_k(E)$, and to its corresponding symbol M_k. But in this case, from the definition of D', 1) $\mathcal{R}_{k+1}$ must be a fibered manifold, 2) to make a choice of connexion c^k_{k+1} we must have the epimorphism $\mathcal{R}_{k+1} \longrightarrow \mathcal{R}_k \longrightarrow 0$, and 3) the system $\mathcal{R}_k$ must be formally transitive, i.e. we must have the epimorphism $\mathcal{R}_k \longrightarrow \mathcal{M} \longrightarrow 0$. Also we shall use the definitions and notations:

$$\mathcal{C}^r_k = \underline{\Lambda^r\, T^*\mathcal{M}} \otimes_\theta R_k / \zeta_k \circ \underline{\delta}(\underline{\Lambda^{r-1}\, T^*\mathcal{M}} \otimes_\theta M_{k+1}).$$

Definition 4 *Let us define* $B^r_k(\mathcal{M})$ *and* $B_k(\mathcal{M})$ *such that*

$$B^r_k(\mathcal{M}) = \underline{\Lambda^r\, T^*\mathcal{M}} \otimes_\theta \underline{J_k},$$

and

$$B_k(\mathcal{M}) = \overset{r}{\oplus} B^r_k(\mathcal{M}).$$

■

$B_k(\mathcal{M})$ has a natural structure of graded $\underline{J_k}$-algebra defined by the exterior product of the J_k-valued forms, since we have the equivalence:

$$B_k(\mathcal{M}) \equiv \underline{\Lambda\, T^*\mathcal{M}} \otimes_\theta \underline{J_k}.$$

$B_k(\mathcal{M})$ inherits also a natural structure of left graded $\Lambda\, T^*\mathcal{M}$-module where the external operation on $\overset{r>0}{\oplus} B^r_k(\mathcal{M})$ is the exterior product $\omega \wedge \mu$ of $\omega \in \Lambda\, T^*\mathcal{M}$ and $\mu \in B_k(\mathcal{M})$ with respect to the pairing on $B^0_k(\mathcal{M})$:

$$([f], [g_k]) \in \theta \times \underline{J_k} \longrightarrow j_k([f]).[g_k] \in \underline{J_k}.$$

Let us denote by $Der_a B_k(\mathcal{M})$ the sheaf of germs of "admissible" graded derivations $\mathcal{D}$ of $B_k(\mathcal{M})$, i.e. if $\mathcal{D}$ is of degree p, one has:

$$\mathcal{D}(\underline{J^0_k}) \subset \underline{\Lambda^p\, T^*\mathcal{M}} \otimes_\theta \underline{J^0_k},$$

$$\mathcal{D}(\underline{\Lambda^r\, T^*\mathcal{M}}) \subset \underline{\Lambda^{r+p}\, T^*\mathcal{M}},$$

where $\underline{J^0_k}$ is the kernel of the target map β_k defined on $\underline{J_k}$:

$$\beta_k : \underline{J_k} \longrightarrow \theta.$$

Obviously $Der_a B_k(\mathcal{M})$ is endowed with the bracket of derivations $[\quad,\quad]$, i.e. if $\mathcal{D}_i$ is a derivation of degree p_i, then we have:

$$[\mathcal{D}_1, \mathcal{D}_2] = \mathcal{D}_1 \circ \mathcal{D}_2 - (-)^{p_1 p_2} \mathcal{D}_2 \circ \mathcal{D}_1.$$

Finally, we also have

$$Der_a B_k(\mathcal{M}) = \overset{r}{\oplus} Der_a^r B_k(\mathcal{M}),$$

where $Der_a^r B_k(\mathcal{M})$ is the module of admissible derivations of degree r on $B_k(\mathcal{M})$.

Definition 5 *One defines $\mathbf{D}_1$ (the "twisting" of $\mathbf{d}$), the non-linear differential operator*

$$\mathbf{D}_1 : \Gamma_{k+1}\mathcal{M} \longrightarrow Der_a^1 B_k(\mathcal{M})$$

such that:

$$\mathbf{D}_1[f_{k+1}] = \mathbf{d} - Ad[f_{k+1}] \circ \mathbf{d} \circ Ad[f_{k+1}^{-1}],$$

where $Ad[f_{k+1}]$ is the contravariant action at the sheafs level of $[f_{k+1}]$ on $\underline{\Lambda\, T^*\mathcal{M}} \otimes_\theta \underline{J_k}$ corresponding to the action of the pull-back of $f \in Aut(\mathcal{M})$ on the tensors of $\Lambda\, T^*\mathcal{M} \otimes J_k$. ∎

To this action on $\Lambda\, T^*\mathcal{M} \otimes J_k$ corresponds simultaneously an action of the "pull-back-push-forward of $f \in Aut(\mathcal{M})$ " on the tensors of $\Lambda\, T^*\mathcal{M} \otimes J_k(\mathcal{M})$. Also, we deduce and define at the sheaf level, the extension of $Ad[f_{k+1}]$ on $\underline{\Lambda\, T^*\mathcal{M}} \otimes_\theta \underline{J_k(\mathcal{M})}$.

Definition 6 *Let*

$$\mathbf{D'}_1 : \Gamma_k\mathcal{M} \longrightarrow \mathcal{C}_k^1(T\mathcal{M}),$$

be "the first non-linear Spencer operator" such that $\forall [f_k] \in \Gamma_k\mathcal{M}$:

$$\mathbf{D'}_1([f_k]) = \rho_k^{k+1} \circ \left[\mathbf{d} - Ad[f_{k+1}] \circ \mathbf{d} \circ Ad[f_{k+1}^{-1}]\right](id_k), \tag{27}$$

where $[f_{k+1}] = c_{k+1}^k([f_k])$ and $id_k \in \underline{J_k(\mathcal{M})}$ is the prolongation up to order k of $id_\mathcal{M} \equiv id_0$. ∎

Sometimes this definition is given using the functor j_1 instead of $\mathbf{d}$. The result is that the derivation is made with respect to the source and not the target and difficulties appear when defining the brackets given further. Then Spencer defined the isomorphism ad of degree zero:

Definition 7 *One defines the isomorphism ad, the operator*

$$ad : \mathcal{C}_{k+1}^\bullet(T\mathcal{M}) \longrightarrow Der_a B_k(\mathcal{M})$$

such that $\forall v \in B_k(\mathcal{M})$ and $\forall u_{k+1} \in \mathcal{C}_{k+1}^r(T\mathcal{M})$:

1. $ad(\mathcal{C}_{k+1}^\bullet(T\mathcal{M})) \overset{def.}{\equiv} Der_\Sigma B_k(\mathcal{M}) = Der_{\Sigma,k}^\bullet \subseteq Der_a B_k(\mathcal{M})$,

2. $\mathcal{L} : \underline{\Lambda\, T^*\mathcal{M}} \otimes_\theta \underline{J_k(T\mathcal{M})} \longrightarrow Der_a B_k(\mathcal{M})$ *being the Lie derivative of degree zero such that*

$$\mathcal{L}(u_k)v = [i(u_k), \mathbf{d}]v \equiv u_k \barwedge \mathbf{d}v + (-)^r \mathbf{d}(u_k \barwedge v),$$

where $\barwedge$ *is the extended Frölicher-Nijenhuis product and* i *the interior product:*

$$i(u_k)v \equiv u_k \barwedge v,$$

3. $ad(u_{k+1})v = \Big[\mathcal{L}(u_k) + (-)^{r+1} D'(u_{k+1})\barwedge\Big]\, v.$

■

Initially, ad is the θ-linear sheafs map corresponding to the $(k+1)$-st order differential operator $\mathcal{L} \circ j_k$ where $\mathcal{L} : J_k(T) \longrightarrow Der_a B_k(\mathcal{M})$ is the Lie derivative of degree zero and of order 1. Then, one obtains the first step of the sophisticated non-linear Spencer complexes associated to the resolutions $\mathcal{C}^\bullet_{k+1}(T\mathcal{M})$ or $Der^\bullet_{\Sigma,k}$:

$$\begin{array}{ccccccc}
1 & \longrightarrow & Aut(\mathcal{M}) & \xrightarrow{j_{k+1}} & \Gamma_{k+1}\mathcal{M} & \xrightarrow{\mathbf{D'}_1} & \mathcal{C}^1_{k+1}(T\mathcal{M}) \\
 & & \| & & \| & & \Big\downarrow{\scriptstyle ad} \\
1 & \longrightarrow & Aut(\mathcal{M}) & \xrightarrow{j_{k+1}} & \Gamma_{k+1}\mathcal{M} & \xrightarrow{\mathbf{D}_1} & Der^1_{\Sigma,k}
\end{array}$$

where the two horizontal sequences are split exact at $\Gamma_{k+1}\mathcal{M}$. From this, we can determine the induced fractional differential operator $\not{\mathbf{D}}'_{\mathbf{1}}$ such that the following diagram is commutative ($M_3 = \widehat{M}_3 = 0$, $\not{M}_2 = 0$):

$$\begin{array}{ccccccccc}
 & & 1 & & 1 & & 0 & & \\
 & & \downarrow & & \downarrow & & \downarrow & & \\
1 & \longrightarrow & \Gamma_G & \xrightarrow{j_2} & \mathcal{R}_2 & \xrightarrow{\mathbf{D'}_1} & \mathcal{C}^1_2 & = & \underline{T^*\mathcal{M}} \otimes_\theta R_2 \\
 & & \downarrow & & \downarrow & & \downarrow & & \\
1 & \longrightarrow & \Gamma_{\widehat{G}} & \xrightarrow{j_2} & \widehat{\mathcal{R}}_2 & \xrightarrow{\widehat{\mathbf{D}}'_1} & \widehat{\mathcal{C}}^1_2 & = & \underline{T^*\mathcal{M}} \otimes_\theta \widehat{R}_2 \\
 & & \downarrow & & \Big\downarrow{\scriptstyle \phi_0} & & \Big\downarrow{\scriptstyle \phi_1} & & \\
1 & \longrightarrow & \theta_{\mathcal{M}} & \xrightarrow{j_1} & \underline{J_1} & \xrightarrow{\not{\mathbf{D}}'_{\mathbf{1}}} & \not{\mathcal{C}}^1_1 & = & B^1_1(\mathcal{M}) \\
 & & & & \downarrow & & \downarrow & & \\
 & & & & 1 & & 0 & &
\end{array} \qquad (28)$$

Obviously, one will determine also ϕ_1 and in the sequel, one will call $B^1_1(\mathcal{M})$ the sheaf of electromagnetic and gravitational gauge potentials.

4. The potentials of interaction and the metric

4.1. The electromagnetic and gravitational potentials

In order to lighten the presentation of the results, first let us consider the following notations:

1) one will merely write f_k and $j_k(f)$ instead of respectively $[f_k]$ and $j_k([f])$,
2) one will denote $T^q f$ the restriction in $\underline{S_q T^*\mathcal{M}} \otimes_\theta \underline{T\mathcal{M}}$ of $[f_p] \in \underline{J_p(\mathcal{M})}$ $(p \geq q \geq 1)$,
3) one will denote $T(T^r f)$ the restriction in $\underline{T^*\mathcal{M}} \otimes_\theta \underline{S_r T^*\mathcal{M}} \otimes_\theta \underline{T\mathcal{M}}$ of $j_1([f_s]) \in \underline{J_1(J_s(\mathcal{M}))}$ $(s \geq r \geq 0)$,
4) one sets analogous conventions concerning the presence of ordinary parenthesis in the notations for the differential of germs of the tangent maps $dT^q f$ and $d(T^q f)$ (let us note in these notations that d is not the exterior differential that one denotes by $\mathbf{d}$, but stands for differential maps).

Then, one has the following set of results $\forall\, \hat{f}_2 \in \widehat{\mathcal{R}}_2$ and $\forall\, X \in \mathcal{C}^1(T\mathcal{M})$:

$$\begin{aligned} Tr^1({}^{j_1(\hat{f}_1)}\nabla_X) &= \frac{1}{2}\sum_{i,j=1}^{n} \tilde{\omega}^{i,j} \Big\{ << d(\omega)\circ\hat{f} | T(\hat{f}).X > | T\hat{f}.e_i \otimes T\hat{f}.e_j > \\ &\quad + 2 < \omega\circ\hat{f} | < d(T\hat{f}) | X > .e_i \otimes T\hat{f}.e_j > \Big\} && (29) \\ &= Tr^1(\nabla_X) + n < \mathbf{d}(\alpha) | X >, && (30) \end{aligned}$$

and

$$\begin{aligned} Tr^1({}^{\hat{f}_2}\nabla_X) &= \frac{1}{2}\sum_{i,j=1}^{n} \tilde{\omega}^{i,j} \Big\{ << d(\omega)\circ\hat{f} | T\hat{f}.X > | T\hat{f}.e_i \otimes T\hat{f}.e_j > \\ &\quad + 2 < \omega\circ\hat{f} | < dT\hat{f} | X > .e_i \otimes T\hat{f}.e_j > \Big\} && (31) \\ &= Tr^1(\nabla_X) + n < \beta | X > . && (32) \end{aligned}$$

Now, let $\widehat{\chi}^{(2)}$ be an element of $\underline{J_1(J_2(T\mathcal{M}))}$, and its components $\widehat{\chi}_q$ $(q = 0, 1, 2)$, i.e. the restrictions of $\widehat{\chi}^{(2)}$ to $\underline{T^*\mathcal{M}} \otimes_\theta \underline{S_q T^*\mathcal{M}} \otimes_\theta \underline{T\mathcal{M}}$ such that $\forall \hat{f}_3 \in \widehat{\mathcal{R}}_3$:

$$\widehat{\chi}^{(2)} = \hat{f}_3^{-1} \circ j_1(\hat{f}_2) - id_3, \tag{33}$$

where by abuse of notations id_3 is the image of $id_3 \in J_3(T\mathcal{M})$ by the canonical injection $J_3(T\mathcal{M}) \longrightarrow J_1(J_2(T\mathcal{M}))$. In particularly, one has the relation (Pommaret 1994):

$$\begin{aligned} \widehat{\chi}_0 &= \hat{f}_1^{-1} \circ j_1(\hat{f}) - id_1 \\ &\equiv \widehat{A} - id_1. \end{aligned}$$

It follows that $\widehat{\mathbf{D}}'_1$ satisfies:

$$\epsilon_1 \circ \widehat{\mathbf{D}}'_1(\hat{f}_2) \equiv \widehat{\tau}^{(2)} = \widehat{\chi}^{(2)} \circ (\widehat{B} \otimes id_2), \tag{34}$$

with $\widehat{B} = \widehat{A}^{-1}$ and $\hat{f}_3 = c_3^2(\hat{f}_2) \in \widehat{\mathcal{R}}_3$. In particular, $\widehat{\tau}_0$ and $\widehat{\tau}_1$ satisfy the relations:

$$\widehat{\tau}_0 = id_{T\mathcal{M}} - T\hat{f} \circ T(\hat{f})^{-1} \equiv id_{T\mathcal{M}} - \widehat{B} = \widehat{\chi}_0 \,.\, \widehat{B} \in T\mathcal{M} \otimes T^{*}\mathcal{M},$$

and $\forall\, X, Y \in T\mathcal{M}$ (Pommaret 1994):

$$< dT\hat{f}|X > \circ\, \widehat{\tau}_0 \,.\, Y + T\hat{f} \circ < \widehat{\tau}_1|Y > .\, X =< d(T\hat{f}) - dT\hat{f}|\widehat{B}.Y > .\, X,$$

where $< dT\hat{f}|X >$, $< \widehat{\tau}_1|Y > \equiv < \widehat{\chi}_1|\widehat{B}.Y >$ and $< d(T\hat{f}) - dT\hat{f}|\widehat{B}.Y >$, are considered as elements of $T\mathcal{M} \otimes T^{*}\mathcal{M}$. Then, if one substitutes

$$T\hat{f}^{-1} \circ T(\hat{f}).X = (\widehat{\chi}_0 + id).X$$

for X in the relations (31)-(32), and also considering the Schwarz equalities:

$$< dT\hat{f}|X > .\, Y =< dT\hat{f}|Y > .\, X,$$

one obtains by subtracting the result from the relations (29)-(30) $\forall\, X \in T\mathcal{M}$:

$$\frac{1}{n} Tr^1 \left[< \widehat{\chi}_1|X > + \nabla_{\widehat{\chi}_0 .X} \right] =< \mathbf{d}(\alpha) - \beta|X > - < \beta|\widehat{\chi}_0.X > . \tag{35}$$

From this latter relation, one can define the electromagnetic potential vector $\widehat{\mathcal{A}} \in \underline{T^{*}\mathcal{M}}$ by $\forall\, X \in \underline{T\mathcal{M}}$:

$$< \widehat{\mathcal{A}}|X >= \frac{1}{n} Tr^1 \left[< \widehat{\tau}_1|X > + \nabla_{\widehat{\tau}_0 .X} \right] =< \mathbf{d}(\alpha)|\widehat{B}.X > - < \beta|X > . \tag{36}$$

In an orthonormal system of coordinates, the latter definition becomes $(i, j, k = 1, ..., n)$:

$$\widehat{\mathcal{A}}_i = \frac{1}{n} \left(\widehat{\tau}^k_{k,i} + \widehat{\tau}^k_{,i} \gamma^j_{j\,k} \right) = \widehat{B}^k_i \partial_k \alpha - \beta_k,$$

where γ is the Riemann-Christoffel 1-form associated to ω and thus satisfying:

$$Tr^1(\nabla_X) = Tr^1(\gamma(X)).$$

Prolonging the relation (35) (one does not prolong the relation (36) because $\widehat{\tau}_2$ is not the first prolongation of $\widehat{\tau}_1$, contrary to $\widehat{\chi}_2$), one deduces and defines the mixed tensor potential of gravitation and electromagnetic $\widehat{\mathcal{B}} \in \overset{2}{\otimes}\underline{T^{*}\mathcal{M}}$ such as $\forall\, X, Y \in T^{*}\mathcal{M}$:

$$\begin{aligned} < \widehat{\mathcal{B}}|Y \otimes X > \;&=\; \frac{1}{n} Tr^1 \left[i_Y < \widehat{\tau}_2|X > + < d(\gamma)|Y \otimes \widehat{\tau}_0.X > \right. \\ &\qquad \left. + \gamma(< \widehat{\tau}_1|X > .\, Y) \right] \\ &=\; < \mathbf{d}(\beta)|\widehat{B}.X \otimes Y > - < \beta| < \widehat{\tau}_1|X > .\, Y > \\ &\qquad - < \mu|X \otimes Y > \end{aligned} \tag{37}$$

where i_Y is the interior product by Y and $\widehat{\tau}_2$ satisfies $\forall\, \hat{f}_3 \in \widehat{\mathcal{R}}_3$ and $\forall\, X, Y, Z \in T\mathcal{M}$:

$$<< d(dT\hat{f}) - d^2T\hat{f}|\widehat{B}.X > |Y \otimes Z >=$$

$$< d^2T\hat{f}|Y \otimes Z > \circ\, \widehat{\tau}_0\, .\, X + < dT\hat{f}|Y > \circ < \widehat{\tau}_1|X > .\, Z$$
$$+ < dT\hat{f}|Z > \circ < \widehat{\tau}_1|X > .\, Y + T\hat{f} \circ << \widehat{\tau}_2|X > |Y \otimes Z > .$$

Again, in an orthonormal system of coordinates $(i, j, k, h = 1, ..., n)$:

$$\widehat{\mathcal{B}}_{j,i} = \frac{1}{n}\left(\widehat{\tau}^k_{k\,j,i} + \widehat{\tau}^k_{j\,,i}\gamma^h_{h\,k} + \widehat{\tau}^k_{,i}(\partial_k\gamma^h_{h\,j})\right) = \widehat{B}^k_i\partial_k\beta_j - \mu_{i\,j} - \widehat{\tau}^k_{j\,,i}\beta_k.$$

This definition for $\widehat{\mathcal{B}}$ hasn't been determined by J.-F. Pommaret (1994), he also gave a different definition for $\widehat{\mathcal{A}}$ rather associated to the relation (35). In conclusion to this chapter, one notices that $\not{D}'_{\mathbf{1}}$ (remaining to explicit) appears to be a Fröbenius-type operator and depends on $\widehat{\tau}^{(1)}$ itself depending on $\widehat{\mathcal{A}}$ and $\widehat{\mathcal{B}}$ as we shall see further. Lastly, ϕ_1 is quite defined by the relations (36) and (37), and if $n = 4$, one has 20 scalar gauge potentials. On the other hand, one can see as well that the definitions of $\widehat{\mathcal{A}}$ and $\widehat{\mathcal{B}}$ can be deduced from the conformal Killing equations on $\underline{J_1(T\mathcal{M})}$, namely $\forall\, \xi_{(1)} \equiv (\xi_0, \xi_1) \in \underline{J_1(T\mathcal{M})}$ and $\forall\, \eta \in \theta$ then one has:

$$K_0(\xi^{(1)}) \overset{def.}{\equiv} \frac{1}{n}Tr^1(\xi_1 + \gamma(\xi_0)) = \eta,$$

where K_0 is the conformal Killing operator. If K_1 is its first prolongation then seting $K^{(1)} \equiv (K_0, K_1)$ one obtains obviously from the equation above $\forall\, X \in \underline{T\mathcal{M}}$ and $\forall\, \widehat{\tau}^{(2)} \in\ \widehat{\mathcal{C}}^1_2(T\mathcal{M})$:

$$\phi_1(\widehat{\tau}^{(2)})(X) = K^{(1)}(< \widehat{\tau}^{(2)}|X >).$$

4.2. The morphisms ϕ_1, $\not{D}'_{\mathbf{1}}$ and the metric of the "gauge space-time"

From the preceding chapter, obviously one easily notices by definition that $\mathcal{C}^1_2$ is the kernel of ϕ_1. On the contrary $\not{D}'_{\mathbf{1}}$, depending on $\widehat{\tau}^{(1)}$, is rather more tricky to determine. The sequences being split and ϕ_1 being θ-linear, one can deduce the important relation that $\widehat{\tau}^{(2)}$ can be rewritten in the following form:

$$\widehat{\tau}^{(2)} = \tau^{(2)} + < \widehat{\mathcal{A}}|\Omega^{(2)} > + < \widehat{\mathcal{B}}|\mathcal{K}^{(2)} >, \tag{38}$$

where $\tau^{(2)} \in \mathcal{C}^1_2$ and $\Omega^{(2)}$ and $\mathcal{K}^{(2)}$ are elements of $\underline{\Lambda\, T^*\mathcal{M}} \otimes_\theta (\widehat{\mathcal{C}}^1_2 \big/ \mathcal{C}^1_2)$, one calls the linear susceptibilities of the vacuum or the space-time associated respectively to $\widehat{\mathcal{A}}$ and $\widehat{\mathcal{B}}$. Then, as a definition of $\not{D}'_{\mathbf{1}}$, one obtains the following kind of relations:

$$\begin{aligned} < a_1|\widehat{\mathcal{A}} > + < b_1|\widehat{\mathcal{B}} > &= D'\alpha \equiv \mathbf{d}\alpha - \beta, \\ < a_2|\widehat{\mathcal{A}} > + < b_2|\widehat{\mathcal{B}} > &= D'\beta \equiv \mathbf{d}\beta - \mu, \end{aligned}$$

where a_1 is affine with respect to $\mathbf{d}\alpha$, b_1 linear with respect to $\mathbf{d}\alpha$, a_2 linear with respect to $\mathbf{d}\beta$ and β, and b_2 affine with respect to $\mathbf{d}\beta$ and β. Thus, $\mathbf{D\!\!\!/}'_{\mathbf{1}}$ is fractional with respect to $\mathbf{d}\alpha$, $\mathbf{d}\beta$, α and β and finally only depends on the susceptibilities of $\widehat{\tau}^{(2)}$. Then, the exactness condition at $\underline{J_1}$:

$$\mathbf{D\!\!\!/}'_{\mathbf{1}} \circ j_1 = 0,$$

the relations (36)-(37) and the commutativity of the diagram (28) involve the necessary condition which must be satified by $\tau^{(2)}$:

$$\tau_0 = 0.$$

There remains the metric ν of the "gauge (or observable or measurable) space-time" defined in considering $\widehat{B}$ as a field of tetrads $\forall\, X, Y \in T\mathcal{M}$:

$$< \nu | X \otimes Y > = < \omega | \widehat{B}.X \otimes \widehat{B}.Y > .$$

Thus, one has the general relation between ν and ω:

$$\nu = \omega + \text{linear and quadratic terms in } \widehat{\mathcal{A}} \text{ and } \widehat{\mathcal{B}}.$$

Then from this metric ν, one can deduce the Riemann and Weyl curvature tensors of the gauge space-time. One has a non-metrical theory for the gravitation in the gauge space-time, since clearly ν doesn't appear as a gravitational potential. The space-time terminology we use is quite natural in the sense that one has simultaneously two types of space-time. The first one, which we call the "underlying" or "substrat" space-time, is endowed with the metric ω and is of constant scalar curvature. The other one, called the "gauge (observable or measurable) space-time", endowed with the metric ν, is defined for any scalar curvature and by the gauge potentials $\widehat{\mathcal{A}}$ and $\widehat{\mathcal{B}}$. It can be considered as the underlying space-time deformed by the gauge potentials and the Weyl curvature does not necessarily vanish, contrary to Pommaret's assertions (Pommaret 1994, see page 456 and Pommaret 1989). Moreover, from a continuum mechanics of deformable bodies point of view, the metric ν can be interpreted as the tensor of deformation of the underlying space-time (Katanaev *et al.* 1992, Kleinert 1989).

5. The fields of interaction

5.1. The second non-linear Spencer operator

Before giving an explicit expression for this operator in the complex of $\underline{J_1}$, one will briefly recall its definition, but before that one needs a few other definitions (Pommaret 1989, Kumpera *et al.* 1972).

Definition 8 *Let the "algebraic bracket"* $\{\ \ ,\ \ \}$ *on* $J_{k+1}(T\mathcal{M})$*, be the* $\mathbb{R}$*-bilinear map* ($\forall k \geq 0$)

$$\{\ \ ,\ \ \} : J_{k+1}(T\mathcal{M}) \times_{\mathcal{M}} J_{k+1}(T\mathcal{M}) \longrightarrow J_k(T\mathcal{M})$$

such as $\forall \xi_{k+1}, \eta_{k+1} \in J_{k+1}(T\mathcal{M})$ *one has:*

$$\{\xi_{k+1}, \eta_{k+1}\} = \{\xi_1, \eta_1\}_{_k},$$

where $\{\xi_1, \eta_1\} \in T\mathcal{M}$ *is the usual Lie bracket defined on* $J_1(T\mathcal{M})$ *and* $\{\xi_1, \eta_1\}_{_k}$ *its lift in* $J_k(T\mathcal{M})$.

■

Definition 9 *One calls "differential Lie bracket" on* $\underline{J_k(T\mathcal{M})}$*, the bracket* $[\![\ ,\ ]\!]$ *such that:*

$$[\![\ ,\ ]\!] : \underline{J_k(T\mathcal{M})} \times_{\mathcal{M}} \underline{J_k(T\mathcal{M})} \longrightarrow \underline{J_k(T\mathcal{M})},$$

and $\forall \xi_k, \eta_k \in \underline{J_k(T\mathcal{M})}$ *then*

$$[\![\xi_k, \eta_k]\!] = \{\xi_1, \eta_1\} + i_{\xi_0} D\eta_{k+1} - i_{\eta_0} D\xi_{k+1},$$

where i *is the usual interior product and* ξ_{k+1} *and* η_{k+1} *are any lifts of* ξ_k *and* η_k *in* $\underline{J_{k+1}(T\mathcal{M})}$.

■

Definition 10 *For any decomposable elements*

$$\alpha = u \otimes \xi_k \in \underline{\Lambda^r T^*\mathcal{M}} \oplus \underline{J_k(T\mathcal{M})},$$

$$\beta = v \otimes \eta_k \in \underline{\Lambda^s T^*\mathcal{M}} \oplus \underline{J_k(T\mathcal{M})},$$

and defining on $\underline{\Lambda T^*\mathcal{M}} \otimes_{_\theta} \underline{J_k(T\mathcal{M})}$ *the interior product* i *by the relation:* $\forall w \in \underline{\Lambda T^*\mathcal{M}}$,

$$i_\alpha w = u \wedge i_{\xi_k} w,$$

then with $\mathbf{d}$ *being the exterior derivative and*

1) $\mathcal{L}$ *the Lie derivative on* $\underline{\Lambda T^*\mathcal{M}} \otimes_{_\theta} \underline{J_k(T\mathcal{M})}$ *such that:*

$$\mathcal{L}(\alpha) = i_\alpha \circ \mathbf{d} + (-)^r \mathbf{d} \circ i_\alpha,$$

2) $ad(\alpha) = \mathcal{L}(\alpha) + (-)^{r+1} i_{_{D\alpha}}$,

one defines the "twisted" bracket on $\underline{\Lambda T^*\mathcal{M}} \otimes_{_\theta} \underline{J_k(T\mathcal{M})}$ *(θ-bilinear),* $[\![\ ,\ ]\!]$ *by the relation:*

$$[\![\alpha, \beta]\!] = [ad(\alpha)v] \otimes \eta_k - (-)^{rs}[ad(\beta)u] \otimes \xi_k + (u \wedge v) \otimes [\![\xi_k, \eta_k]\!] \in \underline{\Lambda^{r+s} T^*\mathcal{M}} \otimes_{_\theta} \underline{J_k(T\mathcal{M})}.$$

■

This bracket defines a graded Lie algebra structure on $\underline{\Lambda T^*\mathcal{M}} \otimes_{_\theta} \underline{J_k(T\mathcal{M})}$.

Definition 11 *One calls 2^{nd} non-linear Spencer operator of the resolution $Der^{\bullet}_{\Sigma,k}$, the differential operator $\mathbf{D}_2$ such that:*

$$\mathbf{D}_2 : Der^1_{\Sigma,k} \longrightarrow Der^2_{\Sigma,k},$$

and $\forall u \in Der^1_{\Sigma,k}$

$$\mathbf{D}_2 u = [\mathbf{d}, u] - \frac{1}{2}[u, u],$$

■

Definition 12 *To this operator $\mathbf{D}_2$ corresponds the 2^{nd} non-linear Spencer operator $\mathbf{D'}_2$ of the resolution $\mathcal{C}^{\bullet}_k(T\mathcal{M})$ such that:*

$$\mathbf{D'}_2 : \mathcal{C}^1_k(T\mathcal{M}) \longrightarrow \mathcal{C}^2_k(T\mathcal{M}),$$

and $\forall \tau \in \mathcal{C}^1_k(T\mathcal{M})$

$$\mathbf{D'}_2 \tau = D'\tau - \frac{1}{2}[\![\tau, \tau]\!]',$$

where $[\![\quad , \quad]\!]'$ *is the quotient twisted bracket.*

■

Definition 13 *With the latter definitions, the "sophisticated non-linear Spencer complex of $\Gamma_{k+1}(\mathcal{M})$", is the truncated split exact differential sequence in the first row of the following commutative diagram of split exact sequences:*

$$\begin{array}{ccccccccc}
1 & \longrightarrow & Aut(\mathcal{M}) & \xrightarrow{j_{k+1}} & \Gamma_{k+1}(\mathcal{M}) & \xrightarrow{\mathbf{D'}_1} & \mathcal{C}^1_{k+1}(T\mathcal{M}) & \xrightarrow{\mathbf{D'}_2} & \mathcal{C}^2_{k+1}(T\mathcal{M}) \\
 & & || & & || & & \downarrow{\scriptstyle ad} & & \downarrow{\scriptstyle ad} \\
1 & \longrightarrow & Aut(\mathcal{M}) & \xrightarrow{j_{k+1}} & \Gamma_{k+1}(\mathcal{M}) & \xrightarrow{\mathbf{D}_1} & Der^1_{\Sigma,k} & \xrightarrow{\mathbf{D}_2} & Der^2_{\Sigma,k}
\end{array}$$

where ad is the isomorphism of graded Lie algebras given in the definition (10), i.e. $\forall \tau, \chi \in \mathcal{C}^{\bullet}_k(T\mathcal{M})$:

$$ad([\![\tau, \chi]\!]') = [ad(\tau), ad(\chi)].$$

■

These sequences can be restricted to $\widehat{\mathcal{R}}_{k+1}$ if $\widehat{\mathcal{R}}_{k+1}$ satisfies the same properties as those given in the sequel of definition (3) concerning D', and moreover if it is 2-acyclic.

5.2. The gravitational and electromagnetic fields

On the one hand, one has the following commutative diagram:

$$\begin{tikzcd}
\underline{J_1} \arrow[r, "\not{\mathbf{D}}'_{\mathbf{1}}"] & \underline{T^*\mathcal{M}}\otimes_\theta \underline{J_1} \\
\widehat{\mathcal{R}}_2 \arrow[u, "\phi_0"'] \arrow[r, "\widehat{\mathbf{D}}'_1"] \arrow[d, equal, "id"] & \widehat{\mathcal{C}}^1_2 \arrow[u, "\phi_1"'] \arrow[d, "ad"] \\
\widehat{\mathcal{R}}_2 \arrow[r, "\widehat{\mathbf{D}}_1"] & Der^1_{\Sigma,a}(\widehat{B}_1)
\end{tikzcd}$$

where $\widehat{B}_1 = \underline{\Lambda\, T^*\mathcal{M}}\otimes_\theta \underline{J_1}$, and on the other hand, one obtains the following relation deduced from the relations (36) and (37): $\forall\,\alpha_1 \in \underline{J_1} \equiv \widehat{B}^0_1$,

$$\not{\mathbf{D}}'_{\mathbf{1}}(\alpha_1) = D'(\alpha_1) - \widehat{\mathbf{D}}_1(\hat{f}_2)(\alpha_1).$$

Also let us define $\widehat{\mathfrak{D}}_1 \equiv \widehat{\mathbf{D}}_1(\hat{f}_2) \in Der^1_{\Sigma,a}(\widehat{B}_1)$ and $\mathfrak{D}$ such that:

$$\mathfrak{D} = D' - \widehat{\mathfrak{D}}_1 \in Der^1_{\Sigma,a}(\widehat{B}_1).$$

It follows one can rewrite:

$$\mathfrak{D}\circ\mathfrak{D} = -\widehat{\mathbf{D}}_2(\widehat{\mathfrak{D}}_1),$$

where $\widehat{\mathbf{D}}_2$ is the 2^{nd} non-linear Spencer operator of the sophisticated Spencer complex of $\widehat{\mathcal{R}}_2$:

$$1 \longrightarrow Aut(\mathcal{M}) \longrightarrow \widehat{\mathcal{R}}_2 \xrightarrow{\widehat{\mathbf{D}}_1} Der^1_{\Sigma,a}(\widehat{B}_1) \xrightarrow{\widehat{\mathbf{D}}_2} Der^2_{\Sigma,a}(\widehat{B}_1).$$

Then, from the definition of $Der^{\bullet}_{\Sigma,k}$, there exists $\widehat{\tau}^{(2)} \in \widehat{\mathcal{C}}^1_2$ such that $\widehat{\mathfrak{D}}_1 = ad(\widehat{\tau}^{(2)})$ and therefore one can write also:

$$\mathfrak{D}\circ\mathfrak{D} = -ad(\widehat{\mathbf{D}}'_2(\widehat{\tau}^{(2)})).$$

Hence $\forall\,\alpha_1 \in \underline{J_1}$ one deduces the relation:

$$\mathfrak{D}\circ\not{\mathbf{D}}'_{\mathbf{1}}(\alpha_1) = -ad(\widehat{\mathbf{D}}'_2(\widehat{\tau}^{(2)}))(\alpha_1),$$

and also $\forall\widehat{\tau}^{(2)} \in \widehat{\mathcal{C}}^1_2$:

$$\begin{aligned}
\mathfrak{D}\circ\phi_1(\widehat{\tau}^{(2)}) &= D'\circ\phi_1(\widehat{\tau}^{(2)}) - \widehat{\mathfrak{D}}_1\circ\phi_1(\widehat{\tau}^{(2)}) \\
&= D'\circ\phi_1(\widehat{\tau}^{(2)}) - ad(\widehat{\tau}^{(2)})\circ\phi_1(\widehat{\tau}^{(2)}) \\
&= D'\circ\tfrac{1}{n}Tr^1(\widehat{\tau}^{(2)}) - ad(\widehat{\tau}^{(2)})\circ\phi_1(\widehat{\tau}^{(2)}) \\
&= \tfrac{1}{n}Tr^1\circ D'(\widehat{\tau}^{(2)}) - ad(\widehat{\tau}^{(2)})\circ\phi_1(\widehat{\tau}^{(2)}) \\
&\overset{def.\,\phi_2}{\equiv} \phi_2\circ D'(\widehat{\tau}^{(2)}) - ad(\widehat{\tau}^{(2)})\circ\phi_1(\widehat{\tau}^{(2)}),
\end{aligned}$$

which can be rewritten:

$$\mathfrak{D} \circ \phi_1(\widehat{\tau}^{(2)}) = \phi_2(\widehat{\mathbf{D}}'_2(\widehat{\tau}^{(2)})) + \frac{1}{2}\phi_2(\llbracket \widehat{\tau}^{(2)}, \widehat{\tau}^{(2)} \rrbracket) - ad(\widehat{\tau}^{(2)}) \circ \phi_1(\widehat{\tau}^{(2)}),$$

where ϕ_2 is the θ-linear morphism:

$$\phi_2 : \widehat{\mathcal{C}}^2_2 \longrightarrow Der^2_{\Sigma,1} \equiv Der^2_{\Sigma,a}(\widehat{B}_1),$$

satisfying the relations: $\forall\, \widehat{\sigma}^{(2)} \in \widehat{\mathcal{C}}^2_2$,

$$\begin{array}{c} \phi_2(\widehat{\sigma}^{(2)}) \equiv \frac{1}{n} Tr^1(\widehat{\sigma}^{(2)}) \\ \text{and} \quad \phi_2 \circ D' = D' \circ \phi_1. \end{array}$$

Then , defining $\not{\mathbf{D}}'_{\mathbf{2}} \overset{def.}{\equiv} \mathfrak{D} \Big/ _{\underline{T^*\mathcal{M}} \otimes_\theta \underline{J_1}}$, we deduce the theorem:

Theorem *The following diagram of differential sequences is commutative, i.e.* $\not{\mathbf{D}}'_{\mathbf{2}} \circ \phi_1 = \phi_2 \circ \widehat{\mathbf{D}}'_2$*:*

$$\begin{tikzcd}
 & 1 \arrow[d] & 1 \arrow[d] & 0 \arrow[d] & 0 \arrow[d] \\
1 \arrow[r] & \Gamma_G \arrow[r, "j_2"] \arrow[d] & \mathcal{R}_2 \arrow[r, "\mathbf{D'}_1"] \arrow[d] & \mathcal{C}^1_2 \arrow[r, "\mathbf{D'}_2"] \arrow[d] & \mathcal{C}^2_2 \arrow[d] \\
1 \arrow[r] & \Gamma_{\widehat{G}} \arrow[r, "j_2"] \arrow[d] & \widehat{\mathcal{R}}_2 \arrow[r, "\widehat{\mathbf{D}}'_1"] \arrow[d, "\phi_0"] & \widehat{\mathcal{C}}^1_2 \arrow[r, "\widehat{\mathbf{D}}'_2"] \arrow[d, "\phi_1"] & \widehat{\mathcal{C}}^2_2 \arrow[d, "\phi_2"] \\
1 \arrow[r] & \theta \arrow[r, "j_1"] & \underline{J_1} \arrow[r, "\not{\mathbf{D}}'_{\mathbf{1}}"] \arrow[d] & \underline{T^*\mathcal{M}} \otimes_\theta \underline{J_1} \arrow[r, "\not{\mathbf{D}}'_{\mathbf{2}}"] \arrow[d] & \underline{\Lambda^2 T^*\mathcal{M}} \otimes_\theta \underline{J_1} \arrow[d] \\
 & & 1 & 0 & 0
\end{tikzcd} \tag{39}$$

if the condition below is satisfied: $\forall\, \widehat{\tau} \in \widehat{\mathcal{C}}^1_2$,

$$\phi_2(\llbracket \widehat{\tau}, \widehat{\tau} \rrbracket) = 2\, ad(\widehat{\tau}) \circ \phi_1(\widehat{\tau}). \tag{40}$$

■

Finally, one notices from a diagram chasing in the diagram (39) that the sequence is exact at $\underline{T^*\mathcal{M}} \otimes_\theta \underline{J_1}$ if and only if one restricts to $Im\, \not{\mathbf{D}}'_{\mathbf{1}}$, i.e. one has only the short split exact sequence:

$$1 \longrightarrow \theta \xrightarrow{\ j_1\ } \underline{J_1} \xrightarrow{\not{\mathbf{D}}'_{\mathbf{1}}} \not{\mathbf{D}}'_{\mathbf{1}}(\underline{J_1}) \xrightarrow{\not{\mathbf{D}}'_{\mathbf{2}}} 0. \tag{41}$$

This might be (?) an illustration of the fondamental theorem of Spencer on the deformations of Lie structures (Spencer 1962, 1965, Goldschmidt 1976a, 1976b, 1978a, 1978b, 1981) since $\underline{J_1}$ is endowed with a Lie group structure.

Let us denote $\widehat{\mathcal{C}}$ and $\pi^{(2)}$ by:

$$\begin{aligned}
\widehat{\mathcal{C}} &\equiv (\widehat{\mathcal{A}},\widehat{\mathcal{B}}) \in \widehat{B}^1_1 = \underline{T^*\mathcal{M}}\otimes_\theta \underline{J_1} \\
\pi^{(2)} &\equiv (\Omega^{(2)},\mathcal{K}^{(2)}) \in \widehat{B}^{1\,*}_1\otimes_\theta(\widehat{\mathcal{C}}^1_2/\mathcal{C}^1_2) \\
\text{and}\qquad & <\widehat{\mathcal{C}}|\pi^{(2)}>\overset{def.}{\equiv}<\widehat{\mathcal{A}}|\Omega^{(2)}>+<\widehat{\mathcal{B}}|\mathcal{K}^{(2)}>=\widehat{\tau}-\tau^{(2)}
\end{aligned}$$

with, as a consequence of the relations (36) and (37):

$$\phi_1(\pi^{(2)}) = 1d_{\widehat{B}^1_1} \in \widehat{B}^{1\,*}_1\otimes_\theta \widehat{B}^1_1 \quad \text{and} \quad \phi_1(\tau^{(2)}) = 0.$$

Then, from (40), one obtains the following equivalent relations:

$$\begin{aligned}
\phi_2([\![\tau^{(2)},\tau^{(2)}]\!]) &= 0 && (42)\\
\phi_2([\![\tau^{(2)},\pi^{(2)})]\!]) &= ad(\tau^{(2)}) && (43)\\
\phi_2([\![\pi^{(2)},\pi^{(2)}]\!]) &= 2\,ad(\pi^{(2)}), && (44)
\end{aligned}$$

which are the defining constraints on the $\tau^{(2)}$ and the susceptibilities $\pi^{(2)}$.

In an orthonormal system of local coordinates, one can write $\not{D}'_{\mathbf{2}}(\widehat{\mathcal{C}}) \equiv (\widehat{\mathcal{G}},\widehat{\mathcal{H}}) = \phi_2(\widehat{\sigma}^{(2)}) \in \underline{\Lambda^2\,T^*\mathcal{M}}\otimes_\theta \underline{J_1} = \widehat{B}^2_1$ in the form $(h,i,j,k,l,r,s = 1,...,n)$:

$$\begin{aligned}
\widehat{\mathcal{G}}_{[i\,j]} &= \tfrac{1}{n}(\widehat{\sigma}^k_{k,[i\,j]} + \widehat{\sigma}^k_{,[i\,j]}\gamma^h_{h\,k}) \\
&\equiv \widehat{B}^k_{[\,i}(\partial_{|\,k\,|}\widehat{\mathcal{A}}_{j\,]}) - \widehat{\mathcal{F}}_{[i\,j]} - \widehat{\tau}^k_{[j,i]}\widehat{\mathcal{A}}_k \\
\widehat{\mathcal{H}}_{j,[k\,i]} &= \tfrac{1}{n}\left(\widehat{\sigma}^h_{h\,j,[k\,i]} + \widehat{\sigma}^l_{j,[k\,i]}\gamma^h_{h\,l} + \widehat{\sigma}^k_{,[k\,i]}(\partial_j\gamma^h_{h\,k})\right) \\
&\equiv \widehat{B}^h_{[\,k}(\partial_{|\,h}\widehat{\mathcal{B}}_{j,|\,i\,]}) - \widehat{\mathcal{E}}_{j\,[k,i]} - \widehat{\tau}^r_{[i,k]}\widehat{\mathcal{B}}_{j,r} - \widehat{\tau}^r_{j,[\,k}\widehat{\mathcal{B}}_{|\,r,|\,i\,]} - \widehat{\tau}^r_{j\,[i,k]}\widehat{\mathcal{A}}_r
\end{aligned}$$

where

1. $\widehat{\mathcal{F}} \in \Lambda^2\,T^*\mathcal{M}$ is the skew-symmetric part of $\widehat{\mathcal{B}}$ one calls the electromagnetic field tensor (or the Faraday tensor),

2. $(\widehat{\mathcal{E}},\widehat{\mathcal{B}},\widehat{\mathcal{A}}) \in \underline{T^*\mathcal{M}}\otimes_\theta \not{R}_2$, i.e. $\forall\, X,Y,Z \in T\mathcal{M}$, $\forall\, c_0 \in \mathbb{R}$,

$$<\widehat{\mathcal{E}}(X,Y)|Z>=\frac{1}{2}<\widehat{\mathcal{B}}(\nabla_X Y + \nabla_Y X)|Z> -c_0\,\omega(X,Y)<\widehat{\mathcal{A}}|Z>,$$

3. $\widehat{\tau}^{(2)}$ satisfies the relation (38).

The terminology one uses for $\widehat{\mathcal{F}}$, comes obviously from the previous relations analogous to those obtained in the Maxwell theory. Indeed, since $(\widehat{\mathcal{G}}, \widehat{\mathcal{H}}) = 0$ because of the exactness condition in the sequence (41), one deduces:

$$\widehat{\mathcal{F}}_{[i\,j]} = \widehat{B}^k_{[\,i}(\partial_{|\,k\,|}\widehat{\mathcal{A}}_{j\,]}) + \widehat{\tau}^k_{[i,j]}\widehat{\mathcal{A}}_k,$$

and from the expression for $\widehat{\mathcal{H}}$:

$$\widehat{B}^h_{[\,k}(\partial_{|\,h}\widehat{\mathcal{F}}_{|\,j,i\,]}) + \widehat{\tau}^r_{[k,j}\widehat{\mathcal{F}}_{i,r]} = 0.$$

In the case of the weak fields limit, the latter become:

$$\begin{cases} \widehat{\mathcal{F}} &= \mathbf{d}\widehat{\mathcal{A}} & \text{(Faraday tensor)} \\ \mathbf{d}\widehat{\mathcal{F}} &= 0 & \text{(Bianchi identity).} \end{cases}$$

On the contrary, the symmetric part $\widehat{\mathcal{P}} \in S_2T^*\mathcal{M}$ of $\widehat{\mathcal{B}}$, called "the gravitational field tensor", satisfies a first order PDE depending on $(\widehat{\mathcal{A}}, \widehat{\mathcal{B}})$, and thus $\widehat{\mathcal{P}}$ varies even if there is only an electromagnetic field! One has to notice that the symmetric part $(\partial_i\widehat{\mathcal{A}}_j)$ is never taken into account in physics, in contradistinction to $\widehat{\mathcal{A}}$. As a result all its derivatives should be physical observables. Finally, one deduces from the exactness of the complex (41) that no current of magnetic charges can exist. In other words, the Bianchi identity must be satisfied. Hence, the lack of magnetic charges can be justified in the framework of the Spencer cohomology of conformal Lie structures but not in the de Rham cohomology framework.

6. The dual linear Spencer complex and the Janet complex

6.1. The dual linear Spencer complex

One shall refer in this chapter to the definitions given in references (Goldschmidt 1976a, 1976b, 1978a, 1978b, 1981, Gasqui *et al.* 1984, Pommaret 1995) relating to the dual linear Spencer complex. Mainly, in this chapter, one has to build up the dual operator ${}^*\not{\mathbf{d}}'_{\mathbf{1}}$ of the infinitesimal operator $\not{\mathbf{d}}'_{\mathbf{1}}$ of $\not{\mathbf{D}}'_{\mathbf{1}}$, and the morphisms L_{n-i} $(i = 0, 1)$ in the commutative diagram:

$$\begin{array}{ccccccccc} 0 & \longrightarrow & \theta_{\mathcal{M}} & \xrightarrow{j_1} & \underline{J_1} & \xrightarrow{\not{\mathbf{d}}'_{\mathbf{1}}} & \not{\mathbf{d}}'_{\mathbf{1}}(\underline{J_1}) \subseteq \not{\mathcal{C}}^{\mathbf{1}}_{\mathbf{1}} & \longrightarrow & 0 \\ & & & & \Big\downarrow{\scriptstyle L_n} & & \Big\downarrow{\scriptstyle L_{n-1}} & & \\ & & & & \not{\mathbf{A}}^{\mathbf{n}}_{\mathbf{1}} & \xleftarrow{{}^*\not{\mathbf{d}}'_{\mathbf{1}}} & \not{\mathbf{A}}^{\mathbf{n-1}}_{\mathbf{1}} & \longleftarrow & 0 \end{array}$$

where the $\not{\mathbf{A}}^{\mathbf{n-i}}_{\mathbf{1}}$ are the dualizing fiber bundles ($\not{\mathcal{C}}^{\mathbf{0}}_{\mathbf{1}} \equiv \underline{J_1}$):

$$\not{\mathbf{A}}^{\mathbf{n-i}}_{\mathbf{1}} = \underline{\Lambda^n\,T^*\mathcal{M}}\otimes_{\theta}{}^*\not{\mathcal{C}}^{\mathbf{i}}_{\mathbf{1}}.$$

One uses a rather classical method to determine the adjoint operators on a connected and oriented compact without boundaries (see P. J. Olver for instance 1986). To this purpose, one gets before a conformally equivariant Lagrangian density $\mathfrak{L}$:

$$\mathfrak{L} : \underline{J_1} \times_{\mathcal{M}} \mathcal{C}^{\mathbf{1}}_{\mathbf{1}} \equiv \mathcal{C}^{\mathbf{0}}_{\mathbf{1}} \times_{\mathcal{M}} \mathcal{C}^{\mathbf{1}}_{\mathbf{1}} \longrightarrow \underline{\Lambda^n T^*\mathcal{M}},$$

and one defines the morphisms L_{n-i} and ${}^*\mathbf{d}'_{\mathbf{1}}$ integrating by parts the infinitesimal variation of $\mathfrak{L}$, with $\mathbf{d}'_{\mathbf{1}}$ defined by $(\alpha_1 \equiv (\alpha, \beta))$:

$$\left\{ \begin{array}{lcl} \widehat{\mathcal{A}} & = & \mathbf{d}\alpha - \beta \\ \widehat{\mathcal{B}} & = & \mathbf{d}\beta - \mu \end{array} \right\} \equiv \mathbf{d}'_{\mathbf{1}}\alpha_1$$

where $\forall\, X, Y \in \mathcal{C}^1(T\mathcal{M})$:

$$\mu(X,Y) = \frac{1}{2}\beta(\nabla_X Y + \nabla_Y X) - c_0\, \alpha\, \omega(X,Y).$$

Let us define in $\mathbf{A}^{\mathbf{n-1}}_{\mathbf{1}}$, the images of $(\widehat{\mathcal{A}}, \widehat{\mathcal{B}})$ by the morphism L_{n-1} with the relations:

$$\left\{ \begin{array}{lcll} \widehat{\mathcal{J}} & = & (\partial \mathfrak{L}/\partial \widehat{\mathcal{A}}) & \text{(electric current)} \\ & & & \\ \widehat{\mathcal{N}} & = & (\partial \mathfrak{L}/\partial \widehat{\mathcal{B}}), & \end{array} \right.$$

and in $\mathbf{A}^{\mathbf{n}}_{\mathbf{1}}$, the images of α_1 by the morphism L_n with the relations:

$$\left\{ \begin{array}{lcll} \hat{\mathcal{S}} & = & (\partial \mathfrak{L}/\partial \alpha) & \text{(density of entropy)} \\ & & & \\ \hat{\mathcal{Q}} & = & (\partial \mathfrak{L}/\partial \beta). & \end{array} \right.$$

One obtains from the infinitesimal variation $\delta\mathfrak{L}$, the following defining relations of ${}^*\mathbf{d}'_{\mathbf{1}}$:

$$\left\{ \begin{array}{lcl} \hat{\mathcal{S}} & = & \mathrm{div}\widehat{\mathcal{J}} - c_0 < \omega | \widehat{\mathcal{N}} > \\ & & \\ \hat{\mathcal{Q}} & = & \widehat{\mathcal{J}} + \mathrm{div}_2\widehat{\mathcal{N}} + < \zeta | \widehat{\mathcal{N}} >, \end{array} \right.$$

where div_2 and ζ are morphisms such as:

$$\begin{array}{rlcl} \mathrm{div}_2 : & \overset{2}{\otimes}\, T\mathcal{M} & \longrightarrow & T\mathcal{M} \\ & u \otimes v & \longrightarrow & v\mathrm{div}(u) - u\mathrm{div}(v) + [u,v] \end{array}$$

and

$$\begin{array}{rlcl} \zeta : & \overset{2}{\otimes}\, \mathcal{C}^1(T\mathcal{M}) & \longrightarrow & \mathcal{C}^0(T\mathcal{M}) \\ & u \otimes v & \longrightarrow & \zeta(u \otimes v) = \gamma(u)v = \gamma(v)u \equiv < \xi \mid u \otimes\ v > . \end{array}$$

From these results, a further step would be to know what the relations between ${}^*\mathbf{d}'_{\mathbf{1}}$ and the thermodynamical laws for the irreversible processes are, since the Lagrangian density $\mathfrak{L}$ depends on temperature and variables of internal states. Hence, $\mathfrak{L}$ might be identified with a Gibbs free enthalpy function, but moreover, setting certain conditions, the conformal equivariance laid down to $\mathfrak{L}$, might also allow us to consider $\mathfrak{L}$ as a wave-function, as we shall see in what follows.

6.2. The Janet complex of the Lagrangian density $\mathfrak{L}$

Again, one refers for the definitions to Pommaret's previous papers (Pommaret 1989, 1994) about the Janet complex and also to Gasqui-Goldschmidt's ones (Gasqui *et al.* 1988), but with an "un-named complex". The conformal equivariance of $\mathfrak{L}$ will merely allow us to obtain explicitly the first Janet operator $\mathbb{D}_1 : \mathcal{F}_0 \longrightarrow \mathcal{F}_1$ where $\mathcal{F}_0$ stands for the line bundle over $\mathcal{C}_{\mathbf{1}}^{\mathbf{0}} \times_{\mathcal{M}} \mathcal{C}_{\mathbf{1}}^{\mathbf{1}}$:

$$\begin{array}{c} \mathcal{F}_0 \\ \Big\downarrow \Big\uparrow \mathfrak{L} \\ \mathcal{C}_{\mathbf{1}}^{\mathbf{0}} \times_{\mathcal{M}} \mathcal{C}_{\mathbf{1}}^{\mathbf{1}} \end{array}$$

From now on, one presents a dependent coordinates formulation choosing an orthonormal system of local coordinates. To make $\mathbb{D}_1$, one must find the transformation rule of $\mathfrak{L}$ by the action of the conformal Lie pseudogroup. Namely, if $\hat{f}_2 \in \widehat{\mathcal{R}}_2$ and $\hat{f}_2^{-1} = \hat{g}_2$, one has the transformation rules:

$$\left\{ \begin{array}{rcl} y & = & \hat{f}(x) \simeq x + \hat{\xi}(x) \\ \alpha' \circ \hat{f} & = & \alpha - \frac{1}{n} \ln |\det J(\hat{f}_1)| \\ \beta'_i \circ \hat{f} & = & \hat{g}_i^j \circ \hat{f}\, [\beta_j - \frac{1}{n} \hat{g}_l^k \circ \hat{f}\, \hat{f}^l_{k\,j}] \\ \widehat{\mathcal{A}}'_i \circ \hat{f} & = & \hat{g}_i^j \circ \hat{f}\, \widehat{\mathcal{A}}_j \\ \widehat{\mathcal{B}}'_{i,j} \circ \hat{f} & = & \hat{g}_i^r \circ \hat{f}\ \hat{g}_j^s \circ \hat{f}\, \widehat{\mathcal{B}}_{r,s} \end{array} \right.$$

and one must have:

$$\mathfrak{L}(\hat{f}, \alpha' \circ \hat{f}, \beta' \circ \hat{f}, \widehat{\mathcal{A}}' \circ \hat{f}, \widehat{\mathcal{B}}' \circ \hat{f}) \det J(\hat{f}_1) = \mathfrak{L}(x, \alpha, \beta, \widehat{\mathcal{A}}, \widehat{\mathcal{B}}). \tag{45}$$

One obtains the infinitesimal condition and the definition of $\mathbb{D}_1$:

$$\mathbb{D}_1(\mathfrak{L}) \equiv \{ v^\mu(\mathfrak{L}) + (\operatorname{div} \xi^\mu)\, \mathfrak{L} \equiv \mathfrak{K} \} = 0,$$

whatever is v^μ ($\mu = 1, ..., \dim \mathfrak{g}_c$), generator of the Lie algebra $\mathfrak{g}_c$ of the conformal Lie group:

$$v^\mu = \hat{\xi}^{\mu,j} \partial_j + \phi^\mu(\alpha) \partial_\alpha + \phi^\mu(\beta_j) \partial_{\beta_j} + \phi^\mu(\widehat{\mathcal{A}}_j) \partial_{\widehat{\mathcal{A}}_j} + \phi^\mu(\widehat{\mathcal{B}}_{k,l}) \partial_{\widehat{\mathcal{B}}_{k,l}},$$

where

$$\left\{\begin{array}{rcl}\phi^\mu(\alpha) & = & -\frac{1}{n}\hat{\xi}^{\mu,k}_k \\ \phi^\mu(\beta_j) & = & -[\hat{\xi}^{\mu,k}_j\beta_k + \hat{\xi}^{\mu,k}_{k\,j}] \\ \phi^\mu(\widehat{\mathcal{A}}_j) & = & -\hat{\xi}^{\mu,k}_j\widehat{\mathcal{A}}_k \\ \phi^\mu(\widehat{\mathcal{B}}_{k,l}) & = & -[\hat{\xi}^{\mu,h}_k\widehat{\mathcal{B}}_{h,l} + \hat{\xi}^{\mu,h}_l\widehat{\mathcal{B}}_{k,h}]\end{array}\right.$$

and $\hat{\xi}^\mu_2 \in \widehat{R}_2$. Moreover, $\mathfrak{K} \equiv (\mathfrak{K}^\mu)$ is transformed like $\mathfrak{L}$ and therefore the zero section of $\mathcal{F}_1$ is defined with $\dim \mathfrak{g}_c = \dim \mathcal{F}_1$ constants c^μ such that $\mathfrak{K}^\mu = c^\mu \mathfrak{L}$ meaning that (45) (or the Lagrangian density) is defined up to a multiplicative constant. The second Janet operator $\mathbf{D}_2$ such as $\mathbf{D}_2 \circ \mathbf{D}_1 = 0$ and $\mathbf{D}_2 : \mathcal{F}_1 \longrightarrow \mathcal{F}_2$, is defined from the involution of the generators of $\mathfrak{g}_c$:

$$[v^\mu, v^\nu] = c^{\mu\,\nu}{}_\lambda\, v^\lambda,$$

where the $c^{\mu\,\nu}{}_\lambda$ are the constants of structure of the $\mathfrak{g}_c$ (see P. J. Olver 1986 for a precise definition of the bracket used above). Thus, one obtains:

$$\mathbf{D}_2(\mathfrak{K}) \equiv \left\{ v^\mu(\mathfrak{K}^\nu) - v^\nu(\mathfrak{K}^\mu) - c^{\mu\,\nu}{}_\lambda\, \mathfrak{K}^\lambda + (\operatorname{div}\hat{\xi}^\mu)\, \mathfrak{K}^\nu - (\operatorname{div}\hat{\xi}^\nu)\, \mathfrak{K}^\mu \right\}.$$

Leading down $\mathfrak{K}^\mu = c^\mu \mathfrak{L}$ in the latter expression, one deduces the following constraints on the constants $c^{\mu\,\nu}{}_\lambda$ of structure:

$$c^{\mu\,\nu}{}_\lambda c^\lambda = 0,$$

with $\mathbf{D}_1(\mathfrak{L})^\mu = c^\mu \mathfrak{L}$.

This latter equation gives in fact only one arbitrary constant among the c^μ's and perhaps might be ascribed to a constant such as the Planck one.

As a particular case, if the metric ω and $\widehat{\mathcal{A}}$ are constants, α and β vanish and $\mathfrak{L}$ function of x and $\widehat{\mathcal{A}}$ only, such that there exists η satifying the relation

$$\widehat{\mathcal{J}}^k = \eta^k \mathfrak{L},$$

then $\forall\, \mu, h$ one has $\hat{\xi}^{\mu,k}_k = \hat{\xi}^{\mu,k}_{k\,h} = 0$ and

$$\left[\hat{\xi}^{\mu,k}\partial_k - (\eta^k \hat{\xi}^{\mu,h}_k)\widehat{\mathcal{A}}_h\right] \mathfrak{L} - c^\mu\, \mathfrak{L} = 0.$$

Thus, one obtains an analogous PDE to the Dirac equation but being equivariant and not only covariant like the Dirac equation. Nevertheless $\mathfrak{L}$ being a real function, it can be interpreted as a wave-function only if one has a definition of a measure of probability. We propose two ways of doing this in the conclusion, and we make suggestions for taking the weak and strong interactions into account in the model.

7. Conclusion

The function $\mathfrak{L}$ being real, let us suggest a notion of mesure of probability. Two of them can be proposed. The first one is related to an "à la Misra-Prigogine-Courbage" (MPC) (Misra *et al.* 1979, Misra 1987) approach. With more details, the wave-function $\mathfrak{S}$ of the model would be the function obtained when applying the integral action of the evolution operator to an initial Lagrangian density $\mathfrak{L}$. First, we thus obtain a wave interpretation. Second, within the MPC theory, the reduction of the wave-paquet (or the collapse) would axiomatically be defined as the achievement of a K-partition of functions $\mathfrak{S}$ on a compact (on which the initial Cauchy data would be defined) of a submanifold of the Minkowski space-time to determine a single function $\mathfrak{S}$. This K-partition of functions $\mathfrak{S}$ would then be a set of new initial Lagrangian densities $\mathfrak{L}$ before any time evolution. The physical measurement thus achieved would not lead us to obtain pure states and with the assumption (to be confirmed) that the conformally equivariant Lagrangian densities $\mathfrak{L}$ would be Kolmogorov flows, it would then be possible, according to the MPC theory, to build up a non-commutative algebra of observables on the analogy of quantum mechanics. Moreover, the K-partition would be achieved on a set of Lagrangian densities of type (m,s) deduced by projection on the basis of the eigenstates of the Poincaré group during the process of measurement (from a certain point of view, the apparatus of measurement, being themselves of the type (m,s)). Thus, as a result of this projection, we shall see a particle state and initial Lagrangian densities of type (m,s) not depending on the fields of interaction anymore. The particle states might be interpreted as a split up of variables between the variable of position x and the fields variables (during specific physical measurements). In other words, one could say that the energy of the fields of interaction would be transfered by radiation to the apparatus of measurement. From a more general point of view, the process of "fragmentation" would be defined by the change from a tensorial Hilbert space to a decomposable Hilbert space ($\mathcal{H}_i$; $i = 1, 2$: Hilbert spaces):

$$\mathcal{H}_1 \otimes \mathcal{H}_2 \longrightarrow \mathcal{H}_1 \oplus \mathcal{H}_2$$

Process that might be interpreted as well as a separation of phase in thermodynamics for the function $\mathfrak{L}$ is similar to a Gibbs function. Under these conditions, the analytical developments of the initial Lagrangian densities define tensors of susceptibility directly associated with the "classical" states of the condensed matter, therefore with the classical notion of macroscopic particles. Thus, the macroscopicity would be associated with the "degree" of separability of the initial densities $\mathfrak{L}$. From our point of view, a second possibility used to define a measure of probability would be to refer to the Penrose approach (Penrose *et al.* 1986) on the complexification of the wave-function in the frame of the theory of twistors, with moreover, the notion of measure of probability defined as it usually is in the first quantization. This procedure is completly different from the one consisting in simply making an algebraic extension from the field of reals to the field of complexes, of the wave-functions satisfying PDE on the field of reals. Such an extension would lead to complex solutions whose real and imaginary parts would each separatly be solutions. Consequently, we assume that a complexification presenting a real interest would give access to the determination of complex solutions which, on the contrary, would be neither their real parts, nor their imaginary ones, solutions for the given system of PDE. To achieve that, Penrose suggested decomposing a problem defined on the real Minkowski space $\mathcal{M}$ into a set of physical subsystems defined on submanifolds of $\mathcal{M}$ and having at least one (complex) spin structure, like the celestial spheres $S^{\pm}$ are, or at fixed time, the sphere S^3. The spin structures are associated with vector bundles like the tangent spaces, or on a rather similar manner (up to the target manifold), the 1-jet bundle $J_1(\epsilon)$ for example. In the present situation, we shall refer to the $\not{\mathbf{d}}'_{\mathbf{1}}(\underline{J_1}) \subseteq \not{\mathcal{C}}^{\mathbf{1}}_{\mathbf{1}}$ bundle over $\underline{J_1}$. We therefore must present the tensors $\widehat{\mathcal{A}}$ and $\widehat{\mathcal{B}}$ with spinors. In the more simple case with only one spin structure (on S^2 for example) and taking up again the Penrose indexed notation, one need at least 3 spinors to decompose the tensor $\widehat{\mathcal{A}}$:

$$\widehat{\mathcal{A}}_a = \alpha_A.\overline{\alpha}_{A'} + \beta_A.\overline{\beta}_{A'} - \gamma_A.\overline{\gamma}_{A'}.$$

For only under these conditions, $\widehat{\mathcal{A}}$ is of any norm, but with a spinor, $\widehat{\mathcal{A}}$ must be of the type light and with two spinors, the norm of $\widehat{\mathcal{A}}$ must be non-negative or non-positive. As far as I know this simple decomposition has never been presented yet (apart from the one with 2 spinors or 3 maximum and with a + mark). But it has indeed a few avantages. First, it is associated (Bars *et al.* 1990) with the representations $\{3\}$ and $\{\bar{3}\}$ of $SU(2,1)$ isomorphic to the one of $SU(3)$. It is only about representations; the group $SU(2,1)$ not being a dynamical gauge group of the model, like for example the Yang-Mills type, but only a group of internal classification and of invariance of the decomposition. The non-compactness of the group cannot appear determining to us within this context. But its finished unitary irreducible representations constructed from the two fundamental representations $\{3\}$ and $\{\bar{3}\}$ only do. Moreover, a symmetry breaking from $SU(2,1)$ to $SU(2)\times U(1)$ or $SU(1,1)\times U(1)$ is associated to a symmetry breaking of type T (for instance during the process of fragmentation) and $\widehat{\mathcal{A}}$ is then of a non-negative or non-positive norm. All of that suggests a possible link with a theory of weak and strong interactions. Before that, formally deriving the spinors decomposing $\widehat{\mathcal{A}}$, we obtain the following decomposition for $\widehat{\mathcal{B}}$ (Penrose *et al.* 1986, see chapter 4.4.7.) using the Leibniz law for the spinors:

$$\widehat{\mathcal{B}}_{a,b} = \alpha_A.\overline{\Gamma}_{B'A',B} + \overline{\alpha}_{A'}.\Gamma_{BA,B'} + \beta_A.\overline{\Theta}_{B'A',B} + \overline{\beta}_{A'}.\Theta_{BA,B'} + \gamma_A.\overline{\Omega}_{B'A',B} + \overline{\gamma}_{A'}.\Omega_{BA,B'},$$

where Γ, Θ and Ω are an any mixed spinors of valence (2,1). They can decompose themselves into irreducible spinors with respect to $SL(2,\mathbb{C})$:

$$\Gamma_{AB,B'} = \Gamma_{(AB),B'} - \frac{1}{2}\epsilon_{[AB]}\Gamma_{C\ \ ,B'}^{\ \ C}$$

(with similar expressions for Θ and Ω). Let us notice that at a given fixed time t and with (α,β) fixed (i.e. during the measure), $SL(2,\mathbb{C})$ being associated with $O^+_{\uparrow}(1,3)$, the irreducibility is thus, according to $SU(2)$, locally with respect to $O(3)$. Moreover, $\Gamma_{(AB),B'}$ is defined by 6 complex components, linearly independant and $\Gamma_{C\ \ ,B'}^{\ \ C}$ by 2 complex components. The interest of such a decomposition appears as soon as the assumption is made that the Lagrangian density $\mathfrak{L}$ is holomorphic in the various spinors on the submanifolds endowed with spin structures. Then $\mathfrak{L}$ satisfies complex PDE deduced from the real PDE defined on $\mathcal{M}$ by lifting on the spinors bundle. But, the physical meaning of the holomorphy is that the physical system can precisely be confined on the submanifolds of M endowed with a spin structure. If we make the physical interpretation that to the spinors decomposing $\widehat{\mathcal{A}}$ and $\widehat{\mathcal{B}}$ are associated some fields of interactions or particles, it means that the latter can only be considered as "free" if they are precisely confined on those submanifolds; the density $\mathfrak{L}$ being then a complex solution on the spinors bundle of the various lifted PDE of the model, from which neither the real part, nor the imaginary part are any solutions. On that subject, one cannot help thinking of the very controversial - and to my knowledge still un-confirmed - Larue *et al.* (1977) and Schaad *et al.* (1981) experiences on "free" quarks confined on bidimensional ($\simeq S^2$) layers of superconducting (!) nobium covering microballs of tungsten (see also Goldman 1995, 1996). Especially because the decomposition presented above could suggest that the simple spinors α, β and γ would be associated with some fields of fermion of mono-colored gluons of spin 1/2 (and not to bi-colored bosons!) and that the symmetric mixed spinors of valence (2,1) would be 3 quarks states of spin 1/2 determined by the 3 contracted spinors $\Gamma_{C}{}^{C}{}_{,B'}$, $\Theta_{C}{}^{C}{}_{,B'}$ and $\Omega_{C}{}^{C}{}_{,B'}$ on which $SU(2,1)$ acts. At last, to finish as well as to come back to an application of the physics of the superconducting states (that some of the theoretical physicists like Mendelstam (1982) or t'Hooft (1978) used to explain the quarks confinement) the question is under which conditions the 4-vector current:

$$\widehat{\mathcal{J}} \ = \ (\partial \mathfrak{L} / \partial \widehat{\mathcal{A}})$$

would be anomalous as well as the Faraday tensor $\widehat{\mathcal{F}}$. A possibility we suggest would be to consider a third metric λ deduced from ν like ν is from ω. The latter metric λ would appear in matter such as in crystals or amorphous materials for instance. Indeed in this case, the second metric ν (and its corresponding potentials and fields) would be associated to the "crystal field" and to a new kind of substrat space-time and new specific succeptibilities. But in the contrary to ω the Weyl curvature associated to ν is no longer necessarly vanishing as we pointed out in a previous chapter. Thus, the corresponding Lie equations for conformal transformations won't be involutive. As a result, the corresponding Spencer sequences and the relative one won't be exact any more as well. In particularly magnetic charges might occur and so anyons (Wilczek 1990). In the framework of symplectic cohomologies of the Lagrangian density $\mathfrak{L}$, it can be shown that the anomalies classification is associated to a second cohomology space knowledge as well as a third one (Cariñena *et al.* 1988). The question remaining to work out would be to know if one can obtain integer cohomologies from these latter in order to exhibit a kind of "quantum structure". To conclude on a more philosophical note, the wave-function model we present here could be interpreted within the framework of a non-Lavoisian chemistry like G. Bachelard (1940) developped. In actual fact, the quantons would not be of "substance", but as Bachelard named them, they would rather be "grains de réaction" and thus, from a certain point of view, like quantons of reactional synthesis or of separation of phase associated with the concept of fragmentation. We also think that this model can't describe global evolution such as a big-bang model but only a local evolution. In some ways as G. Deleuze *et al.* (1980) say about their striated space (like a substrat space-time) and smooth space concepts (see chapters: "12.1227. Traité de nomadologie: la machine de guerre" and "11.1837. De la ritournelle"), "one can only know the path by exploring it". Also, the form concept for matter in space-time could be related to a boundary being the geometrical set of places onto which the "grains de réaction" occur.

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High Temperature Superconductivity

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Abstract

The current status of basic research on the high temperature cuprate superconductors and prospects for technological applications of these materials is discussed. Recent developments concerning other novel superconductors are also briefly described.

Keywords:
Superconductivity – high-T_c, superconductors – ceramic, correlations – electronic, order parameter

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Introduction

The discovery of superconductivity at ~30 K in the La-Ba-Cu-O system by Bednorz and Müller in 1986 [1] ignited an explosion of interest in high temperature superconductivity. These initial developments rapidly evolved into an intense worldwide research effort that still persists after more than a decade, fueled by the fact that high temperature superconductivity constitutes an extremely important and challenging intellectual problem and has enormous potential for technological applications. During the past decade of research on this subject, significant progress has been made on both the fundamental science and technological applications fronts. For example, the symmetry of the superconducting order parameter and the identity the superconducting electron pairing mechanism appear to be on the threshold of being established, and prototype superconducting wires that have current carrying capacities in high magnetic fields that satisfy the requirements for applications are being developed. Prospects seem to be good for attaining a fundamental understanding of high temperature superconductors and realizing technological applications of these materials on a broad scale during the next decade.

The purpose of this paper is to provide a brief overview of the current status of the field of high temperature superconductivity. The emphasis is on experiment and recent developments on the high superconducting critical temperature (T_c) cuprates. Topics discussed include: (1) materials, (2) structure and charge carrier doping, (3) normal state properties, (4) symmetry of the superconducting order parameter, and (5) prospects for technological applications. At the end of the article, we describe recent progress involving other novel superconducting materials.

The immense scope of this subject dictated a very selective choice of the examples cited to illustrate the progress made in this field over the past decade. For comprehensive accounts of specific topics in high temperature superconductivity, the reader is referred to various review articles, such as those that appear in the series of volumes edited by

Ginsberg [2]. Because of space limitations, it was also not possible to discuss the fascinating subject of vortex phases and dynamics which has flourished since the discovery of the cuprate superconductors [3].

High T_c superconducting cuprates

The dramatic increases in T_c that have been observed since 1986 are illustrated in Fig. 1 where the maximum value of T_c is plotted vs. date. Prior to 1986, the A15 compound Nb_3Ge with $T_c \approx 23$ K held the record for the highest value of T_c [4]. The maximum value of T_c has increased steadily since 1986 to its present value of ~133 K for a compound in the Hg-Ba-Ca-Cu-O system [5,6]. When this compound ($HgBa_2Ca_2Cu_3O_8$) is subjected to a high pressure, the T_c onset increases to ~164 K (more than half way to room temperature!) at pressures ~30 GPa [7,8]. While $HgBa_2Ca_2Cu_3O_8$ cannot be used in applications of superconductivity at such high pressures, this striking result suggests that values of T_c in the neighborhood of 160 K, or even higher, are attainable in cuprates at atmospheric pressure.

Values of T_c in excess of the boiling temperature of liquid nitrogen (77 K) immediately implicated high T_c cuprates as promising candidates for technological applications of superconductivity. Whereas liquid helium is currently employed to cool conventional superconducting materials such as Nb, NbTi, and Nb_3Sn into the superconducting state (Nb is employed in SQUIDs and NbTi and Nb_3Sn are used to make superconducting wires), the cuprate materials have the advantage that they can be cooled into the superconducting state using liquid nitrogen. Cuprates such as the $LnBa_2Cu_3O_{7-\delta}$ (Ln = lanthanide) compounds (T_c in the range 92-95 K) have enormous critical fields ~10^2 tesla [9,10] that are more than adequate for technological applications. Epitaxially grown thin films of $YBa_2Cu_3O_{7-\delta}$ on single crystal $SrTiO_3$ substrates have critical current densities $J_c \approx 10^6$A/cm^2 in zero field which decrease relatively slowly with magnetic field, making them suitable for technological applications [11]. Unfortunately, polycrystalline bulk materials have J_c's that are disappointingly low, ~10^3 - 10^4 A/cm, and are strongly depressed by a magnetic field [12]. The situation can be improved substantially by subjecting $YBa_2Cu_3O_{7-\delta}$ to a melt textured growth process which yields values of J_c of ~10^5 A/cm at 77 K that are not too strongly depressed by an applied magnetic field [13]. Fortunately, techniques have recently been devised which yield values of J_c in high fields for in-plane grain oriented thin films of $YBa_2Cu_3O_{7-\delta}$ on flexible substrates at 64 K (pumped liquid nitrogen temperatures) that exceed those of NbTi and Nb_3Sn at liquid helium temperatures [14]. These promising developments are briefly described near the end of this article.

The materials

Approximately 100 different cuprate materials, many of which are superconducting, have been discovered since 1986. Several of the more important high T_c cuprate superconductors are listed in Table 1, along with the maximum values of T_c observed in each class of materials. Included in the table are examples of abbreviated designations (nicknames) for specific cuprate materials which we will use throughout this article (e.g., $YBa_2Cu_3O_{7-\delta}$ = YBCO, YBCO-123. Y-123). High quality polycrystalline, single crystal and thin film specimens of these materials have been prepared and investigated extensively to determine their fundamental normal and superconducting state properties. Presently, two of the leading candidates for technological applications of superconductivity are the $LnBa_2Cu_3O_{7-\delta}$ and $Bi_2Sr_2Ca_2Cu_3O_{10}$ materials.

Structure and charge carrier doping

The high T_c cuprate superconductors have layered perovskite-like crystal structures which consist of conducting CuO_2 planes separated by layers comprised of other elements A and oxygen, A_mO_n, and, in some cases, layers of Ln ions [15,16]. The mobile charge carriers, which can be electrons but are usually holes, are believed to reside primarily within the CuO_2 planes. The A_mO_n layers apparently function as charge reservoirs and control the doping of the CuO_2 planes with charge carriers. In several of the compounds containing Ln layers, the Ln ions with partially-filled 4f electron shells and magnetic moments have been found to order antiferromagnetically at low temperature [9,12].

Many of the cuprates can be doped with charge carriers and rendered superconducting by substitution of appropriate elements into an antiferromagnetic insulating parent compound. For example, substitution of divalent Sr for trivalent La in the antiferromagnetic insulator La_2CuO_4 dopes the CuO_2 planes with mobile holes and produces superconductivity in $La_{2-x}Sr_xCuO_4$ with a maximum T_c of ~40 K at $x \approx 0.17$ [17]. Similarly, substitution of tetravalent Ce for trivalent Nd in the antiferromagnetic insulating compound Nd_2CuO_4 apparently dopes the CuO_2 planes with electrons, resulting in superconductivity in $Nd_{2-x}Ce_xCuO_{4-y}$ with a maximum T_c of ~25 K at $x \approx 0.15$ for $y \approx 0.02$ [18,19]. The temperature T vs x phase diagrams for the $La_{2-x}Sr_xCuO_4$ and $Nd_{2-x}Ce_xCuO_{4-y}$ systems are shown in Fig. 2 [19], and the corresponding crystal structures of the La_2CuO_4 and Nd_2CuO_4 parent compounds are displayed in Fig. 3. The $La_{2-x}Sr_xCuO_4$ and $Nd_{2-x}Ce_xCuO_{4-y}$ systems have one CuO_2 plane per unit cell and are referred to as single CuO_2 layer compounds. Other superconducting cuprate systems have more than one CuO_2 plane per unit cell: $LnBa_2Cu_3O_{7-\delta}$ has two CuO_2 planes per unit cell (double CuO_2 layer compound), while $Bi_2Sr_2Ca_{n-1}Cu_nO_x$ has n CuO_2 layers per unit cell (n CuO_2 layer compound) and can be synthesized by conventional methods for n = 1, 2, 3.

Two features in Fig. 2 would appear to be relevant to cuprate superconductivity: (1) the apparent electron-hole symmetry may provide a constraint on viable theories of high T_c superconductivity in cuprates, and (2) the proximity of antiferromagnetism suggests that superconducting electron pairing in the cuprates may be mediated by antiferromagnetic spin fluctuations. An antiferromagnetic pairing mechanism is consistent with the occurrence of d-wave pairing with $d_{x^2-y^2}$ symmetry that is suggested by experiments on several hole-doped cuprates (discussed later in this article). A number of theoretical models (e.g., [20-22]) based on AFM spin fluctuations predict d-wave superconductivity with $d_{x^2-y^2}$

symmetry for the cuprates. Surprisingly, as discussed below, experiments on the electron-doped superconductor $Nd_{2-x}Ce_xCuO_{4-y}$ suggest s-wave pairing similar to that of conventional superconductors where the pairing is mediated by phonons.

It is interesting that superconductivity with values of T_c in the neighborhood of 30 K have been found in two noncuprate materials: the cubic perovskite $Ba_{1-x}K_xBiO_3$ ($T_c \approx 30$ K) [23,24] and the fcc "buckeyball" compound Rb_3C_{60} ($T_c \approx 29$ K) [25,26]. Other features are consistent with non-phonon-mediated pairing in the hole-doped cuprates. The curve of T_c vs carrier concentration can be approximated by an inverted parabola with the maximum value of T_c occurring at an optimal dopant concentration x_o [27]. (Note that the terminology "under-doped" refers to values of x smaller than the "optimally-doped" value x_o, whereas "over-doped" refers values of x larger than x_o.) The isotope effect on T_c for optimally-doped material is essentially zero (i.e., $T_c \propto M^{-\alpha}$ with $\alpha \approx 0$; M = ion mass) [28].

Normal state properties

It was realized at the outset that the normal state properties of the high T_c cuprate superconductors are unusual and appear to violate the Landau Fermi liquid paradigm [29-32]. Some researchers share the view that in so far as the normal state properties reflect the electronic structure that underlies high T_c superconductivity, it will be necessary to develop an understanding of the normal state before the superconducting state can be understood.

The anomalous normal state properties first identified in the high T_c cuprate superconductors include the electrical resistivity and Hall effect. The electrical resistivity $\rho_{ab}(T)$ in the ab-plane of many of the hole-doped cuprate superconductors near optimal doping has a linear temperature dependence between T_c and high temperatures ~1000 K, with an extrapolated residual resistivity $\rho_{ab}(0)$ that is very small; i.e., $\rho_{ab}(T) \approx \rho_{ab}(0) + cT$, with $\rho_{ab}(0) \approx 0$ and the value of c similar within different classes of cuprate materials [33]. The Hall coefficient R_H is inversely proportional to T and the cotangent of the Hall angle $\theta_H = R_H/\rho$ varies as T^2; i.e., $\cot(\theta_H) \equiv \sigma_{xx}/\sigma_{xy} = AT^2 + B$ [34]. The linear T-dependence of $\rho(T)$ and the quadratic T-dependence of $\cot(\theta_H)$ have been attributed to longitudinal and transverse scattering rates τ_l^{-1} and τ_t^{-1} that vary as T and T^2, respectively [35]. In the RVB model, the constant and T^2 terms in τ_t^{-1} and, in turn, $\cot(\theta_H)$, are ascribed to scattering of spinons by magnetic impurities and other spinons, respectively. Examples of the linear T-dependence of $\rho(T)$, inverse T-dependence of R_H, and quadratic T-dependence of $\cot(\theta_H)$ near optimal doping ($x \approx 0$) can be found in Figs. 4(a), 5(a), and 5(b) in which ρ_{ab}, R_H^{-1}, and $\cot(\theta_H)$ vs T data are displayed for the $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ system [36-38]. Experiments in which Ca^{2+} ions are counterdoped with Pr for Y in $YBa_2Cu_3O_{7-\delta}$ indicate that the Pr ions localize holes at a rate of ~one hole per substituted Pr ion [37]. Thus, as x is increased, the $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ system becomes more and more under-doped and T_c decreases, vanishing near the metal-insulator transition that occurs at $x_{mi} \approx 0.55$. Displayed in Fig. 4(b) is the T-x phase diagram for the $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ system which reveals the behavior of $T_c(x)$ as well as the Néel temperatures $T_N(x)$ for AFM ordering of Cu and Pr magnetic moments. It has been argued that the depression of T_c with x is primarily due to the decrease in the number of mobile holes with increasing Pr concentration, although magnetic pair breaking by Pr may also be involved [37,38]. In contrast, both $\rho_{ab}(T)$ and $\rho_c(T)$ of the optimally-doped electron-doped cuprate $Sm_{1.83}Ce_{0.17}CuO_{4-y}$ vary as T^2, indicative of three dimensional Fermi liquid behavior [39].

The evolution of the normal ground state of the cuprates as a function of dopant concentration is particularly interesting. This is reflected in the temperature dependences of the ab-plane and c-axis electrical resistivities $\rho_{ab}(T)$ and $\rho_c(T)$ [40]. Both $\rho_{ab}(T)$ and $\rho_c(T)$ exhibit insulating behavior (i.e., $d\rho/dT < 0$) in the under-doped region, $\rho_{ab}(T)$ is metallic (i.e., $d\rho/dT > 0$) and $\rho_c(T)$ is insulating or metallic in the optimally-doped region, depending on the system, and $\rho_{ab}(T)$ and $\rho_c(T)$ are both metallic in the over-doped region. The linear T-dependence of $\rho_{ab}(T)$ and the insulating behavior of $\rho_c(T)$ suggest two dimensional non Fermi liquid behavior near the optimally-doped region, whereas the metallic $\rho(T) \propto T^n$ with $n > 1$ reflects a tendency towards three dimensional Fermi liquid behavior in the over-doped region. Recent measurements in 61-tesla pulsed magnetic fields to quench the superconductivity have been particularly useful in elucidating the evolution of $\rho_{ab}(T)$ and $\rho_c(T)$ with dopant concentration in the $La_{2-x}Sr_xCuO_4$ system [41]. Both $\rho_{ab}(T)$ and $\rho_c(T)$ were found to exhibit -ln T divergences in the under-doped region, indicative of a three dimensional non Fermi liquid [42]. As an example of the evolution of $\rho_{ab}(T)$ and $\rho_c(T)$ with doping, we again refer to the $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ system. Shown in Fig. 6 are $\rho_{ab}(T)$ and $\rho_c(T)$ data for $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ single crystals in the range of Pr concentrations $0 \leq x \leq 0.55$ [43]. The following features in the $\rho_{ab}(T)$ and $\rho_c(T)$ data in Fig. 6 are evident: a nonmonotonic evolution of $\rho_c(T)$ with x, the transformation of both $\rho_{ab}(T)$ and $\rho_c(T)$ from metallic to semiconducting with x, and the coexistence of metallic $\rho_{ab}(T)$ and semiconducting $\rho_c(T)$ for a certain range of doping. The nonmonotonic variation of $\rho_c(T)$ with x in Fig. 6(b) can be described with a phenomenological model [43] which assumes that the c-axis conductivity takes place via incoherent elastic tunneling between CuO_2 bilayers and CuO chain layers with a gap in the energy spectrum of the CuO chains (solid lines in Fig. 6(b)).

Perhaps the most remarkable aspect of the normal state is the pseudogap in the charge and spin excitation spectra of under-doped cuprates [44,45]. The pseudogap has been inferred from features in various transport, magnetic, and thermal measurements including $\rho_{ab}(T)$ [46,47,48], $R_H(T)$ [49], thermoelectric power S(T) [50], NMR Knight shift K(T) [51], NMR spin-lattice relaxation rate $1/T_1(T)$ [52,53,54], magnetic susceptibility $\chi(T)$ [49], neutron scattering [55], and specific heat C(T) [56], as well as spectroscopic measurements such as infrared absorption [57,58,59] and angle resolved photoemission spectroscopy ARPES [60,61]. An example of the features in $\rho_{ab}(T)$ that are associated with the pseudogap can be seen in the $\rho_{ab}(T)$ data displayed in Figs. 4(a) and 6(a) for the $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ system. As the system becomes more under-doped with increasing x, $\rho_{ab}(T)$ deviates from linear behavior at higher temperature at a characteristic temperature T* which represents a crossover into the pseudogap state at $T < T^*$. The transport, thermal, magnetic, and infrared studies of the pseudogap have been carried out on several cuprate materials, including LSCO, YBCO-123, YBCO-124, and BSCCO-2212, while the ARPES investigations of the pseudogap have mainly focussed on BSCCO, although ARPES measurements have also been made on oxygen-deficient YBCO.

The ARPES measurements reveal several striking aspects of the pseudogap. The magnitude of the pseudogap has the same k-dependence in the ab-plane as the magnitude of the superconducting energy gap, with maxima in the directions of k_x and k_y and minima at 45˚ to these directions. In fact, the symmetry is consistent with $d_{x^2-y^2}$ symmetry inferred from Josephson tunneling measurements on hole-doped cuprates discussed in the next section. Furthermore, measurements of the temperature dependence of the pseudogap at the angles where it is a maximum show that the superconducting gap grows continuously out of the pseudogap and that the value of the sum of both gaps at low temperatures is constant, independent of the temperature T* at which the pseudogap opens, or T_c. This is in marked contrast to the situation in conventional superconductors where the energy gap is proportional to T_c. These features are illustrated in Figs. 7(a) and (b) which show the k-dependence of the energy gap and the dependence of the maximum gap on temperature from the ARPES measurements of Ding et al. [60] on BSCCO-2212 samples wirh T_c's of 87 K, 83 K, and 10 K. The pseudogap and the superconducting energy gap appear to be intimately related to one another, with the former the precursor of the latter. These results support the view that a unified theory of both the normal and superconducting states of the cuprates is imperative. The pseudogap and superconducting regions for the BSCCO-2212 derived from the ARPES measurements of Ding et al. [60] are shown in Fig. 8. Based upon investigations on LSCO, YBCO-123 and -124, BSCCO, and other systems, one can construct a generic T-x phase diagram which is shown schematically in Fig. 9. The phase diagram is very rich and contains insulating, antiferromagnetic, superconducting, pseudogap, two dimensional (2D) non Fermi liquid like, and three dimensional (3D) Fermi liquid like regions.

A number of models and notions have been proposed to explain the part of the phase diagram delineated by the curves of T* and T_c vs x (e.g., [62–67]). Generally, these models involve the local pairing of electrons (or holes) at the temperature T* leading to a suppression of the low lying charge and spin excitations and the formation of the normal state pseudogap, followed by the onset of phase coherence at T_c that results in superconductivity. Since the phenomenon of superconductivity involves coherent pairing, a bell shaped curve of T_c vs x results as shown schematically in Fig. 10. For example, in resonating valence bond (RVB) models [30,62,63,64,67] which incorporate spin - charge separation into "spinons" with spin s = 1/2 and charge q = 0 and "holons" with s = 0 and q = +e, where e is the charge of the electron, the spinons become paired (spin pseudogap) at T* and coherent pairing of holons (Bose-Einstein condensation) occurs at T_d, resulting in superconductivity.

Symmetry of the superconducting order parameter

During the last several years, a great deal of effort has been expended to determine the symmetry of the superconducting order parameter of the high T_c cuprate superconductors [68,69]. The pairing symmetry provides clues to the identity of the superconducting pairing mechanism which is essential for the development of the theory of high temperature superconductivity in the cuprates.

Shortly after the discovery of high T_c superconductivity in the cuprates, it was established from flux quantization, Andreev reflection, Josephson effect, and NMR Knight-shift measurements, that the superconductivity involves electrons that are paired in singlet spin states [70]. Possible orbital pairing states include s-wave, extended s-wave, and d-wave states. In the s-wave state, the energy gap $\Delta(\mathbf{k})$ is <u>isotropic</u>; i.e., $\Delta(\mathbf{k})$ is constant over the Fermi surface. This leads to "activated" behavior of the physical properties in the superconducting state for $T \ll \Delta$; e.g., the specific heat $C_e(T)$, ultrasonic attenuation coefficient $\alpha_s(T)$, and NMR spin lattice relaxation rate $1/T_1(T)$ vary as $\exp(-\Delta/T)$. For the extended s-wave state, the energy gap $\Delta(T)$ is anisotropic; i.e., $\Delta(\mathbf{k})$ exhibits a variation over the Fermi surface which has the same symmetry as the rotational symmetry of the crystal. Similarly, for the d-wave case, the energy gap $\Delta(\mathbf{k})$ is anisotropic, but with a symmetry that is lower than the symmetry of the crystal. The d-wave state that is consistent with most of the experiments discussed below has $d_{x^2-y^2}$ symmetry, which can be expressed as $\Delta(\mathbf{k}) = \Delta_o[\cos(k_x a) - \cos(k_y a)]$. For both the extended s-wave and d-wave cases, $\Delta(\mathbf{k})$ vanishes at lines on the Fermi surface, resulting in a density of states $N_s(E)$ that is linear in energy E at low values of E. This leads to "power law" T^n (n = integer) behavior of the physical properties for $T << \Delta$; e.g., $C_e(T) \sim T^2$, the superconducting penetration depth $\lambda(T) \sim T$, and $1/T_1(T) \sim T^3$. The establishment of the symmetry of the superconducting order parameter requires the determination of both the magnitude and the phase of $\Delta(\mathbf{k})$. Shown in Fig. 11 is a schematic diagram of the variation of the energy gap over the Fermi surface and the density of states N(E) vs E for the "s", extended "s", and "d"$_{x^2-y^2}$ states [68].

A number of different types of measurements have been performed on the high T_c cuprate superconductors which are sensitive to $|\Delta(\mathbf{k})|$. These include microwave penetration depth $\lambda(T)$ [71], microwave surface conductivity [72], NMR relaxation rate $1/T_1(T)$ [73], magnetic field dependence of the electronic specific heat $C_e(T)$ [74], thermal conductivity [75], ARPES [76], quasiparticle tunneling [77,78], and Raman scattering [79]. The results of these studies are generally consistent with a superconducting state with $d_{x^2-y^2}$ or extended s-wave symmetry for the hole-doped cuprates such as YBCO-123, 124, LSCCO, and BSCCO, and s-wave symmetry for the electron-doped superconductor NCCO [80,81,82]. However, the experiments discussed below indicate a dominant component of $d_{x^2-y^2}$ symmetry in the superconducting order parameter of hole-doped cuprates. This is a rather surprising result, considering the similarities in the structures of the hole-doped and electron-doped superconductors and the fact that they are both derived from chemical substitution of antiferromagnetic insulating parent compounds.

Several different types of measurements which are sensitive to the phase of $\Delta(\mathbf{k})$ have been performed. These measurements, all of which involve the Josephson effect, include SQUID interferometry [83,84,85], single junction modulation [86,87], tricrystal ring magnetometry [88,89,90], c-axis Josephson tunneling [91,92,93,94,95], and grain boundary tunneling [96]. The SQUID interferometry, single junction modulation, and tricrystal ring magnetometry measurements were performed on YBCO, while tricrystal magnetometry experiments have also been carried out on TBCCO. These experiments indicate that the superconducting order parameter in the YBCO and TBCCO hole-doped materials has $d_{x^2-y^2}$ symmetry. However, c-axis Josephson tunneling studies on junctions consisting of a conventional superconductor (Pb) and twinned or untwinned single crystals of YBCO indicate that the superconducting order parameter of YBCO has a significant s-wave component [91,92]. Shown in Fig. 12 are Josephson critical current vs magnetic field B data for an untwinned YBCO/Pb tunnel junction at 4.2 K for B||a and B||b [92]. From the geometry of the junction, independent measurements of the penetration depth of Pb, and the period of the $I_c(B)$ Fraunhofer patterns, the YBCO penetration depths λ_a = 1307 Å and λ_b = 1942 Å were obtained. The large anisotropy ratio $(\lambda_a/\lambda_b)^2 \leq 2$ suggests significant pair condensation on the Cu-O chains in YBCO.

Recently, a new class of c-axis Josephson tunneling experiments in which a conventional superconductor (Pb) was deposited across a single twin boundary of a YBCO single crystal were performed by Kouznetsov et al. [97]. The Josephson critical current I_c was then measured as a function of magnitude and angle ϕ of magnetic field applied in the plane of the sample. For B aligned perpendicular to the twin boundary, a maximum in I_c as a function of B was observed at B = 0, similar to the case of the untwinned YBCO single crystal data shown in Fig. 12, whereas for B parallel to the twin boundary, a minimum in I_c was observed at B = 0. In all samples investigated, a clear experimental signature of an order parameter phase shift across the twin boundary was observed. The results provide strong evidence for mixed d- and s-wave pairing in YBCO and are consistent with predominant d-wave pairing with $d_{x^2-y^2}$ symmetry and a sign reversal of the s-wave component across the twin boundary.

An experiment that provides evidence for a multicomponent superconducting order parameter in YBCO was recently reported by Srikanth et al [98]. Microwave measurements on YBCO single crystals prepared in $BaZrO_3$ (BZO) crucibles [99] yielded new features in the temperature dependence of the microwave surface resistance and penetration depth in the temperature range $0.6 \leq T/T_c \leq 1$ which the authors suggest constitute evidence for a multicomponent superconducting order parameter. These features were not observed in microwave measurements on YBCO single crystals prepared with yttria stabilized zirconia (YSZ) crucibles, suggesting that YBCO single crystals prepared in BZO crucibles are of higher quality than those prepared in YSZ crucibles [99].

Technological Applications of Superconductivity

Technological applications of superconductivity can be divided into two major areas: superconducting electronics and superconducting wires and tapes. While the widespread use of high T_c cuprate superconductors in technology has not yet been realized, steady and significant progress has been made towards this objective during the past decade. Recent developments indicate that high T_c cuprate superconductors will begin to have a significant impact on technology during the next 5 to 10 years. The applications in superconducting electronics that are likely to be realized on this time scale have been summarized in a recent article by Rowell [100]. In the order in which they are anticipated, these applications include: SQUIDS, NMR coils, wireless communications subsystems, MRI coils and NMR microscopes, and digital instruments. In the area of superconducting wires and tapes, applications that appear to be feasible within this same time period include: power transmission lines, motors and generators, transformers, current limiters, magnetic energy storage, magnetic separation, research magnet systems, and current leads.

An example of recent progress in the area of superconducting wires and tapes is the development of flexible superconducting ribbons consisting of deposits of YBCO on textured substrates which have critical current densities $J_c \sim 10^6 A/cm^2$ in fields up to 8T at 64 K, a temperature that can be achieved by pumping on liquid nitrogen [14]. The performance of these prototype conductors in strong magnetic fields already surpasses that of NbTi and Nb_3Sn, which are currently used in commercial superconducting wires at liquid helium temperatures, in a comparable field range. The YBCO tapes are based on processes developed at two U. S. Department of Energy (DOE) National Laboratories, Los Alamos (LANL) and Oak Ridge (ORNL), under the DOE's National Superconductivity Program for Electric Power Applications. The essential step in both the LANL and ORNL processes is the preparation of a textured substrate, or "template," onto which a thick film of YBCO is deposited with well-aligned YBCO grains, that match the alignment of the underlying substrate. The alignment of the YBCO grains results in the high critical current density.

The LANL process, which is an extension of earlier work done at Fujikura Ltd. in Japan, uses a technique called "ion beam assisted deposition," or IBAD, to produce a preferentially oriented buffer layer on top of commercial nickel alloys, such as Hastelloy. The IBAD method uses four beams of charged particles to grow YSZ crystals with only one particular orientation on top of a ceramic oxide-buffered Hastelloy tape. Because of the excellent lattice match between YBCO and YSZ, the YBCO grains are "in-plane aligned" like the grains of the underlying YSZ layer.

The ORNL process involves fabricating long lengths of biaxially-textured metal (e.g., nickel) strips. Oxide buffer layers are then deposited on top of the metal substrate in order to transfer the alignment to the superconducting layer, while avoiding chemical degradation. The ORNL substrate technology is referred to as "RABiTS," or rolling-assisted, biaxially-textured substrates. In both the LANL and ORNL processes, pulsed laser deposition (PLD) is used to deposit the superconducting YBCO layer and some of the buffer layers.

Shown in Fig. 13 is the magnetic field dependence of the critical current density for the IBAD and RABiTS based YBCO coated samples recently produced at LANL and ORNL. These coated samples operated in the liquid nitrogen temperature range clearly outperform the metallic superconductors (NbTi, Nb_3Sn) at 4.2 K. Furthermore, even in the worst field direction (H || c), and for temperatures below 65 K, the short sample YBCO coated conductors operated in a 8-tesla background field have at least an order of magnitude higher J_c than pre-commercial BSCCO-2223 wire with no applied field.

The high T_c YBCO coated tapes have been shown to be extremely flexible and to retain the high current carrying capacity, so that they appear to be suitable for wound magnet and coil applications. A significant challenge that remains is the development of efficient, continuous commercially viable processes for fabricating long lengths of these high current carrying in-plane aligned YBCO coated conductors with uniform properties.

Other superconducting materials

Although the high T_c cuprates have been the focus of research on superconducting materials during the past decade, a number of other noteworthy novel superconducting materials have been discovered during this period. A few examples are briefly described below.

Rare earth transition metal borocarbides

Superconductivity was discovered in a series of compounds with the formula RNi_2B_2C with a maximum T_c of 16.5 K for R = Lu [101,102]. These materials have attracted a great deal of interest because they display both superconductivity and magnetic order and effects associated with the interplay of these two phenomena, similar to the RRh_4B_4 and RMo_6X_8 (X = S, Se) ternary superconductors that were studied extensively during the '70's and early '80's [103]. Investigations of superconducting and magnetic order and their interplay have been greatly facilitated by the availability of large single crystals of these materials [104]. Recently, values of T_c that rival the T_c = 23 K value of the intermetallic compound Nb_3Ge, the high T_c record holder for an intermetallic compound, have been found in mixed phase materials of the composition YPd_5B_3C (T_c = 23 K) [105] and $ThPd_3B_3C$ (T_c = 21 K, $H_{c2}(0) \approx 17$ T) [106].

Sr_2RuO_4

The superconducting compound Sr_2RuO_4 has the same structure as the $La_{2-x}M_xCuO_4$ (M = Ba, Sr, Ca; Na) high T_c cuprate superconductors [107]. While the T_c of Sr_2RuO_4 is only ~1K, this compound is of considerable interest because it is the only layered perovskite superconductor without Cu. The anisotropy of the superconducting properties of Sr_2RuO_4 is very large ($\gamma = \xi_{ab}/\xi_c \approx 26$). Although this anisotropy is larger than that of $La_{2-x}M_xCuO_4$, the in-plane and c-axis resistivities of Sr_2RuO_4 vary as T^2 at low temperature, indicative of Fermi liquid behavior. It has been suggested that Sr_2RuO_4 may exhibit p-wave superconductivity [108].

Alkali-metal doped C_{60}

Exploration of the physical properties of materials based on the molecule C_{60} revealed superconductivity with relatively high values of T_c in metal-doped C_{60} compounds [109]. For example, the fcc compounds K_3C_{60} and Rb_3C_{60} have T_c's of 18 K and 29 K, respectively [25,26].

LiV_2O_4

The metallic transition metal oxide LiV_2O_4, which has the fcc normal-spinel structure, has been found to exhibit a crossover with decreasing temperature from localized moment to heavy Fermi liquid behavior [110], similar to that which has been observed in strongly correlated f-electron materials [111]. At 1 K, the electronic specific heat coefficient $\gamma \approx 0.42$ J/mol K^2, is exceptionally large for a transition metal compound. No superconducting or magnetic order was detected in this compound to temperatures as low as ~0.01 K. This behavior can be contrasted with that of the isostructural compound

$LiTi_2O_4$ which displays nearly T-independent Pauli paramagnetism and superconductivity with T_c = 13.7 K [112].

Quantum Spin Ladder materials

Quantum spin ladder materials have attracted much recent interest [113,114]. These materials consist of ladders made of AFM chains of S = 1/2 spins coupled by inter-chain AFM bonds. Examples of 2-leg ladder materials are $SrCu_2O_3$ and $LaCuO_{2.5}$; an example of a 3-leg ladder material is $Sr_2Cu_2O_5$. Superconductivity has apparently been discovered in the ladder material $Sr_{0.4}Ca_{13.6}Cu_{24}O_{41.84}$ under pressure with $T_c \approx 12$ K at 3 GPa [115]. Part of the interest in quantum spin ladder materials stems from the fact that they are simple model systems for theories of superconductivity based on magnetic pairing mechanisms.

Concluding remarks

During the past decade, remarkable progress in the areas of basic research and technological applications has been made on the high T_c cuprate superconductors. The availability of high quality polycrystalline and single crystal bulk and thin film materials has made it possible to make reliable measurements of the physical properties of these materials and to optimize superconducting properties (e.g., J_c) that are important for technological applications. These investigations have provided important information regarding the anomalous normal state properties, the symmetry of the superconducting order parameter, and vortex phases and dynamics in the cuprates. The next decade of research on the high T_c cuprate superconductors as well as other novel superconducting materials promises to yield significant advances toward the development of a theory of high temperature superconductivity as well as the realization of technological applications of these materials on a broad scale. It is possible that significantly higher values of T_c will be found in new cuprate compounds or other classes of materials. Nature may even have some more surprises in store for us, as it did in 1986!

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Table caption

Table 1.

(a) Some important classes of cuprate superconductors and the maximum value of T_c observed in each class.

(b) Examples of the abbreviated designations (nicknames) used to denote cuprate materials.

Figure captions

Fig. 1.

Maximum superconducting critical temperature T_c vs date.

Fig. 2.

Temperature-dopant concentration (T-x) phase diagram delineating the regions of superconductivity and antiferromagnetic ordering of the Cu^{2+} ions for the hole-doped $La_{2-x}Sr_xCuO_4$ and electron-doped $Nd_{2-x}Ce_xCuO_{4-y}$ systems. AFM = antiferromagnetic phase, SG = spin-glass phase, and SC = superconducting phase. After Reference [19].

Fig. 3.

Crystal structures of La_2CuO_4 (T-phase) and Ln_2CuO_4 (Ln = Pr, Nd, Sm, Eu, Gd; T'-phase) parent compounds. From Reference [19].

Fig. 4.

(a) In-plane electrical resistivity ρ_{ab} vs temperature T curves for $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ ($0 \le x \le 0.51$) single crystals. From Reference [36].

(b) Temperature T vs Pr concentration x phase diagram for tthe $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ system, delineating metallic, superconducting, insulating, and antiferromagnetically ordered regions. From References [36,37].

Fig. 5.

(a) Temperature dependence of the Hall carrier number $n_H = V/eR_H$ vs temperature T for $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ single crystals with different x values. From Reference [36].

(b) Cotangent of the Hall angle $\cot(\theta_H)$ vs T^2 for $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ single crystals with different x values. Inset: Slope A and intercept B vs T. From Reference [36].

Fig. 6.

(a) In-plane resistivity $\rho_{ab}(T)$ and (b) out-of-plane resisitivity $\rho_c(T)$ for $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ single crystals. The solid lines in (b) are fits to the data using a model described in Reference [43]. Inset to Fig. 6(a): The configuration of leads used in the measurements. Inset to Fig. 6(b): Anisotropy ρ_c/ρ_{ab} vs Pr concentration x at different temperatures. The solid lines are guides to the eye. From Reference [43].

Fig. 7.

Momentum and temperature dependence of the energy gap estimated from leading edge shifts of ARPES spectra for BSCCO-2212. (a) k-dependence of the gap in the T_c = 87 K, 83 K, and 10 K samples, measured at 14 K. The inset shows the Brillouin zone with a large Fermi surface (FS) closing the (π,π) point, with the occupied region shaded. (b) Temperature dependence of the maximum gap in a near-optimal T_c = 87 K sample (circles), and underdoped T_c = 83 K (squares) and T_c = 10 K (triangles) samples. From Reference [60].

Fig. 8.

Schematic phase diagram of BSCCO-2212 as a function of doping. The filled symbols represent the T_c's determined from magnetic susceptibility measurements. The open symbols are the T*'s at which the pseudogap closes derived from the data shown in Fig. 7. From Reference [60].

Fig. 9.

Generic temperature T - dopant concentration x phase diagram for cuprates (schematic). The solid lines labelled T_N and T_c delineate the antiferromagnetic (AFM) and superconducting regions, respectively. The "hatched" line denoted T* represents the crossover into the pseudogap state.

Fig. 10.

Schematic temperature T - dopant concentration x phase diagram for the cuprates. The dashed line labelled T* represents the temperature below which some type of local pairing occurs leading to a suppression of low energy excitations and the formation of the pseudogap. The solid line labelled T_ϕ denotes the temperature below which phase coherence develops, resulting in superconductivity. The dark solid line labelled T_c delineates the superconducting region.

Fig. 11.

Fermi surface gap functions and densities of states of a superconductor with tetragonal symmetry for various pairing symmetries. The gap functions in the $k_z = 0$ plane (top) are represented by the light solid lines; distance from the Fermi surface (dark solid lines) gives the amplitude, a positive value being outside the Fermi surface, a negative value inside. The corresponding density of states for one-quasiparticle excitations N(E) is shown below each gap function, with N_o the normal state value. Gap node surfaces are represented by the dashed lines. Left: The classic s-wave case, where the gap function is constant, with value Δ. This gives rise to a square-root singularity in N(E) at energy E = Δ. Middle: The extended s-wave case derives from pairs situated on nearest-neighbor square lattice sites in real space, with an approximate k-space form of $\cos(k_x a) + \cos(k_y a)$. For the Fermi surface shown here, the gap function has lines of nodes running out of the page. Right: A d-wave function of $x^2 - y^2$ symmetry. The extended s-wave and d-wave functions shown here each have a linear density of states up to order Δ, which measures the maximum gap amplitude about the Fermi surface. From Reference [68].

Fig. 12.

Josephson critical current I_c vs magnetic field B for c-axis Josephson tunneling between an untwinned $YBa_2Cu_3O_{7-\delta}$ single crystal and a Pb counterelectrode for B||a (upper curve) and B||b (lower curve). The upper curve is offset by 0.5 mA along the y-axis. From Reference [92].

Fig. 13.

Magnetic field dependence of the critical current density for a range of short sample YBCO conductors produced using either IBAD or RABIT substrates. These data are compared with typical values obtained for NbTi and Nb_3Sn wires at 4.2 K and for BSCCO, oxide-powder-in-tube wires at 77K. From Reference [14].

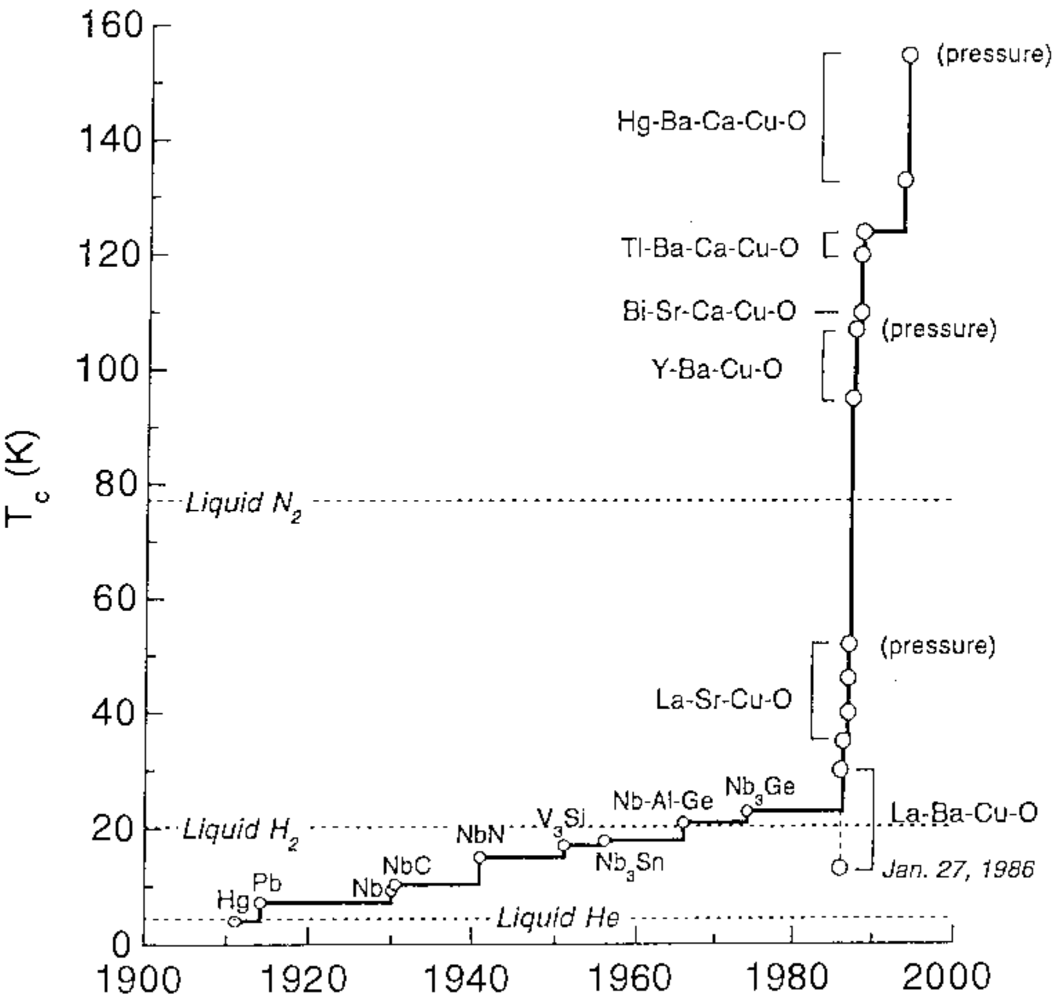
Table 1. (a) Some important classes of cuprate superconductors and the maximum value of T_c observed in each class. (b) Examples of the abbreviated names (nicknames) used to denote cuprate materials.

(a)

Material			Max. T_c(K)
• $La_{2-x}M_xCuO_4$; M = Ba, Sr, Ca, Na			~40
• $Ln_{2-x}M_xCuO_{4-y}$; Ln = Pr, Nd, Sm, Eu; M = Ce, Th			~25
• $YBa_2Cu_3O_{7-\delta}$			92
• $LnBa_2Cu_3O_{7-\delta}$ Ce, Tb do not form phase Pr forms phase; neither metallic nor SC'ing			~95
• $RBa_2Cu_4O_8$			~80
• $Bi_2Sr_2Ca_{n-1}Cu_nO_{2n+4}$	(n = 1,2,3,4)	(n = 3)	110
• $TlBa_2Ca_{n-1}Cu_nO_{2n+3}$	(n = 1,2,3,4)	(n = 4)	122
• $Tl_2Ba_2Ca_{n-1}Cu_nO_{2n+4}$	(n = 1,2,3,4)	(n = 3)	122
• $HgBa_2Ca_{n-1}Cu_nO_{2n+2}$	(n = 1,2,3,4)	(n = 3)	133

(b)

Material	Nickname	T_c(K)
• $YBa_2Cu_3O_{7-\delta}$	YBCO; YBCO–123; Y–123	92
• $Bi_2Sr_2Ca_2Cu_3O_{10}$	BSCCO; BSCCO–2223; Bi–2223	110
• $Tl_2Ba_2Ca_2Cu_3O_{10}$	TBCCO; TBCCO–2223; Tl–2223	122
• $HgBa_2Ca_2Cu_3O_8$	HBCCO; HBCCO–1223; Hg–1223	133
• $La_{1.85}Sr_{0.15}CuO_4$	LSCO	40
• $Nd_{1.85}Ce_{0.15}CuO_{4-y}$	NCCO	25



160
140
120
100
80
60
40
20
0
1900
1920
1940
1960
1980
2000
T c (K)
Liquid N 2
Liquid H 2
Liquid He
(pressure)
Hg-Ba-Ca-Cu-O
Tl-Ba-Ca-Cu-O
Bi-Sr-Ca-Cu-O
(pressure)
Y-Ba-Cu-O
(pressure)
La-Sr-Cu-O
La-Ba-Cu-O
Jan. 27, 1986
Hg
Pb
Nb
NbC
NbN
V 3 Si
Nb 3 Sn
Nb-Al-Ge
Nb 3 Ge

Fig. 1

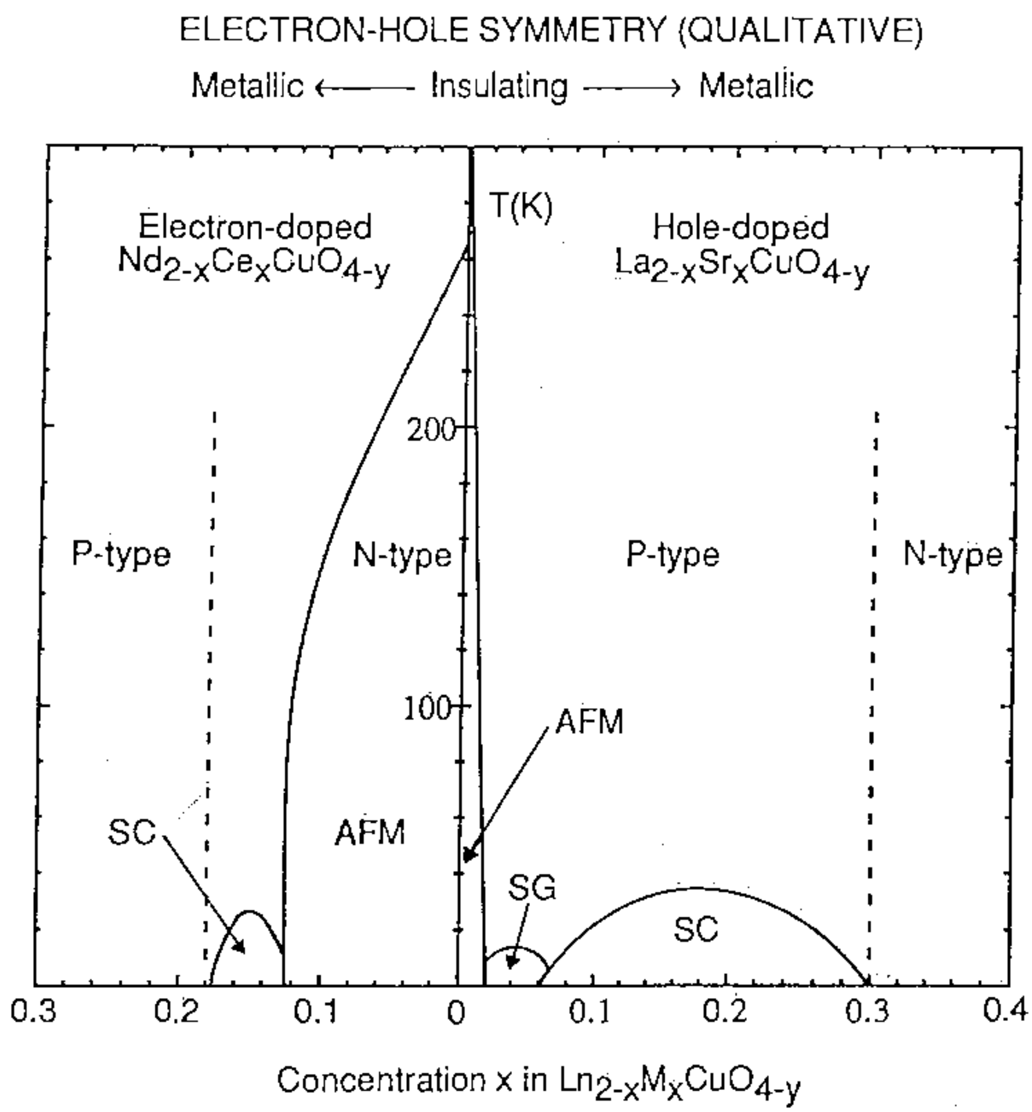

ELECTRON-HOLE SYMMETRY (QUALITATIVE)
Metallic ⟵ Insulating ⟶ Metallic
T(K)
Electron-doped
$Nd_{2-x}Ce_xCuO_{4-y}$
Hole-doped
$La_{2-x}Sr_xCuO_{4-y}$
200
100
P-type
N-type
P-type
N-type
AFM
AFM
SC
SG
SC
0.3
0.2
0.1
0
0.1
0.2
0.3
0.4
Concentration x in $Ln_{2-x}M_xCuO_{4-y}$

Fig. 2

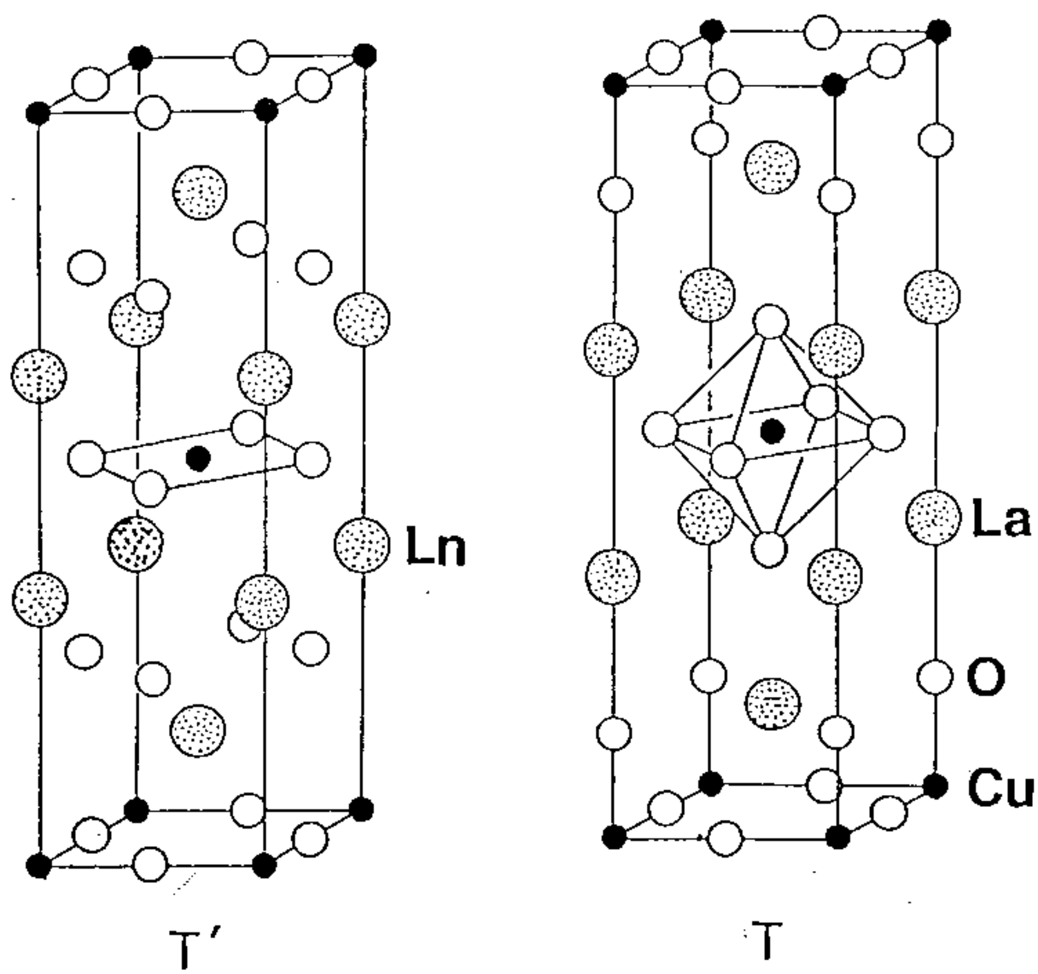
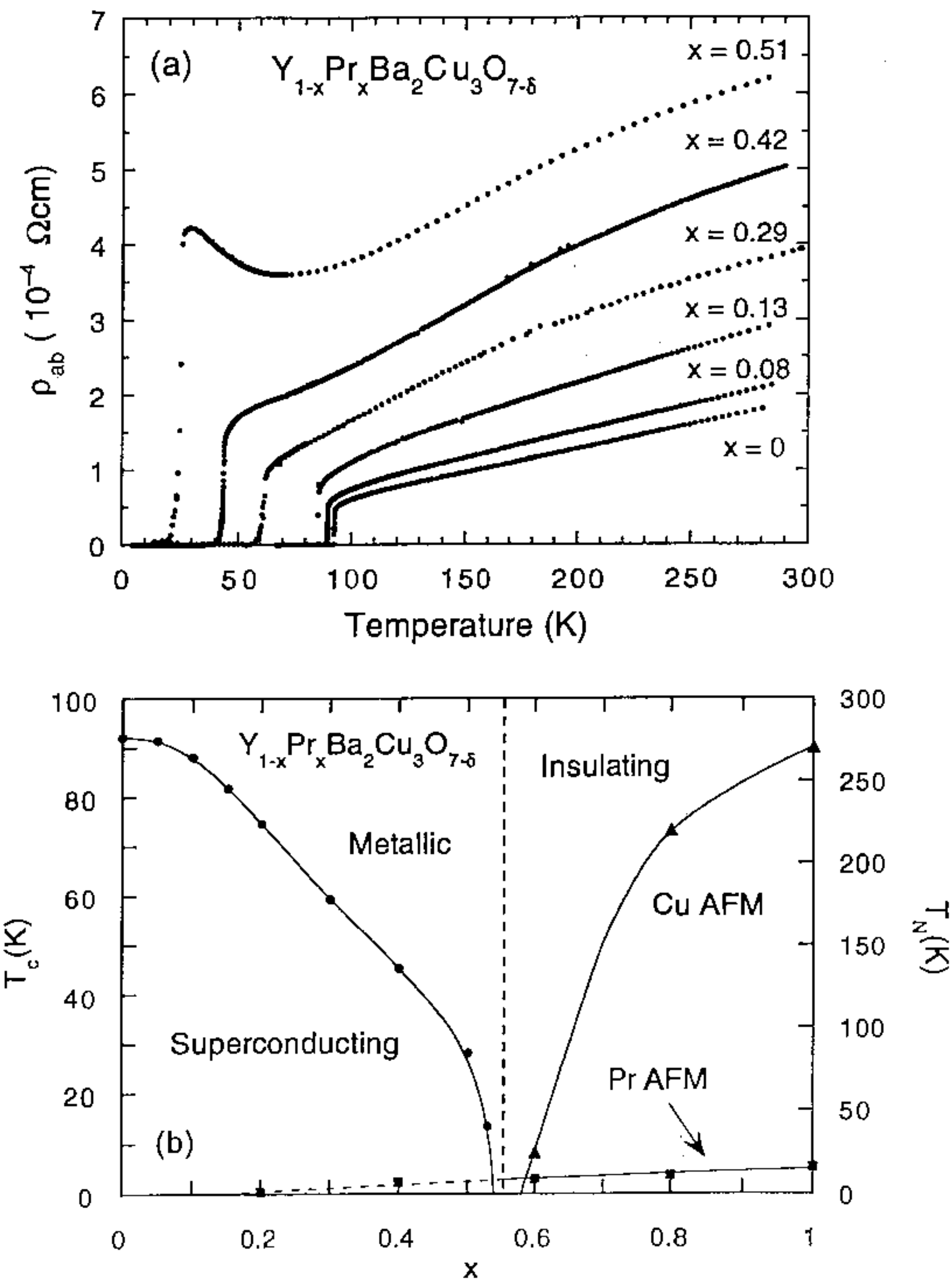
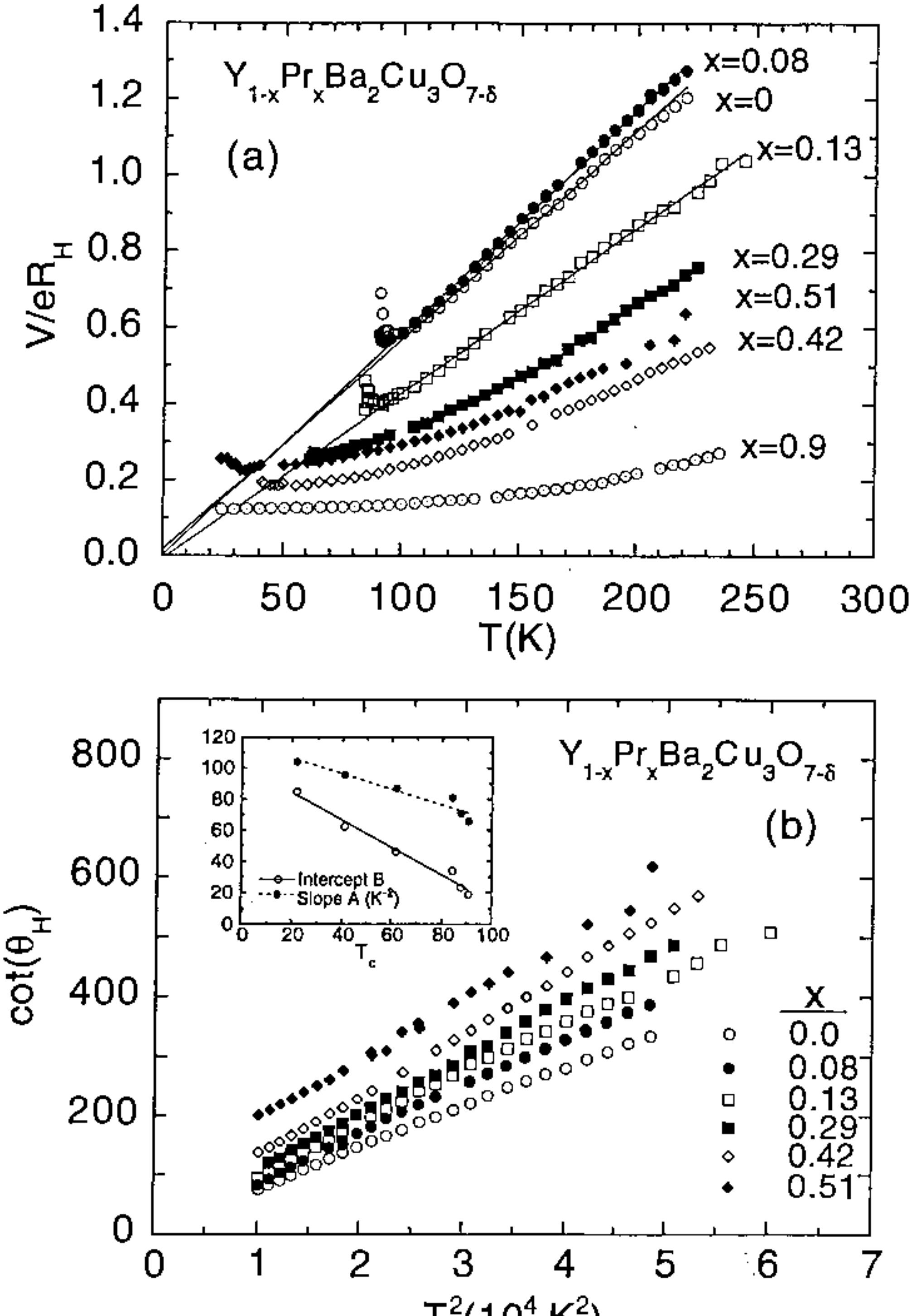


Fig. 3



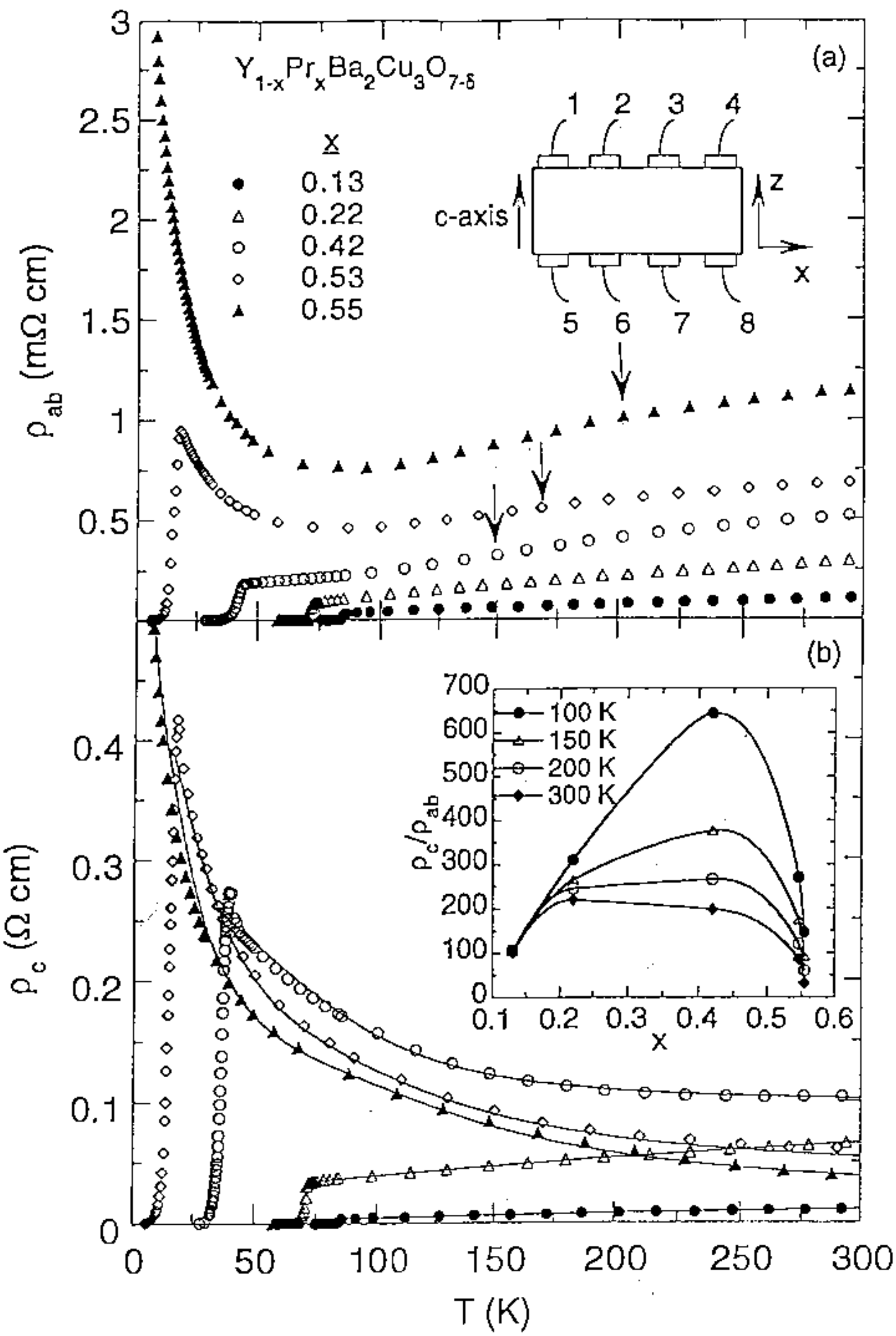
(a)
$Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$
x = 0.51
x = 0.42
x = 0.29
x = 0.13
x = 0.08
x = 0
ρ_{ab} (10^{-4} Ωcm)
Temperature (K)
(b)
$Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$
Insulating
Metallic
Cu AFM
Superconducting
Pr AFM
T_c(K)
T_N(K)
x

Fig. 4



Y1-xPrxBa2Cu3O7-δ
(a)
x=0.08
x=0
x=0.13
x=0.29
x=0.51
x=0.42
x=0.9
V/eRH
T(K)
(b)
Intercept B
Slope A (K-2)
Tc
x
0.0
0.08
0.13
0.29
0.42
0.51
cot(θH)
T2(104 K2)

Fig. 5



(a)
$Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$
x
0.13
0.22
0.42
0.53
0.55
1
2
3
4
5
6
7
8
c-axis
z
x
ρ_{ab} (mΩ cm)
(b)
100 K
150 K
200 K
300 K
ρ_c/ρ_{ab}
x
ρ_c (Ω cm)
T (K)

Fig. 6

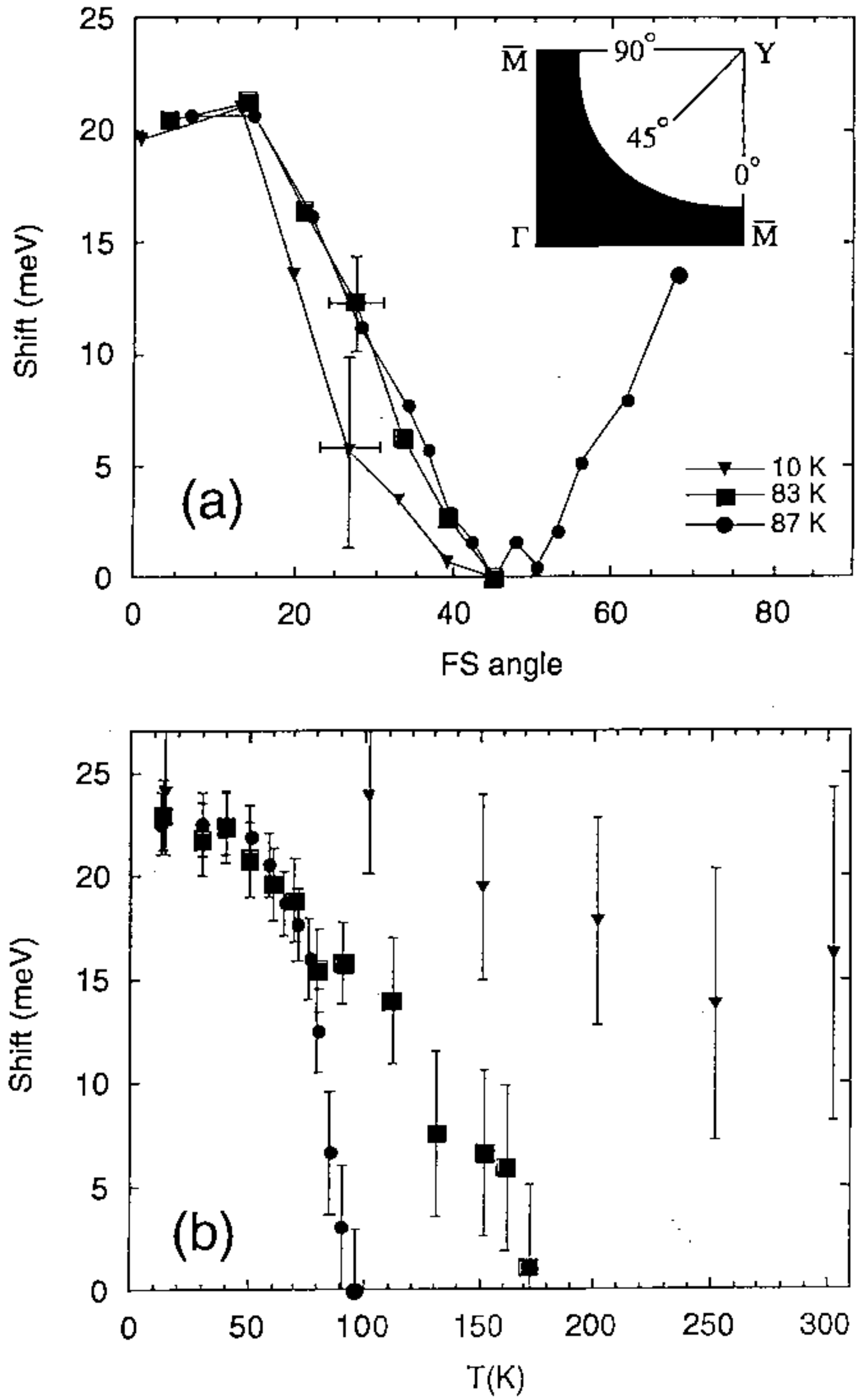
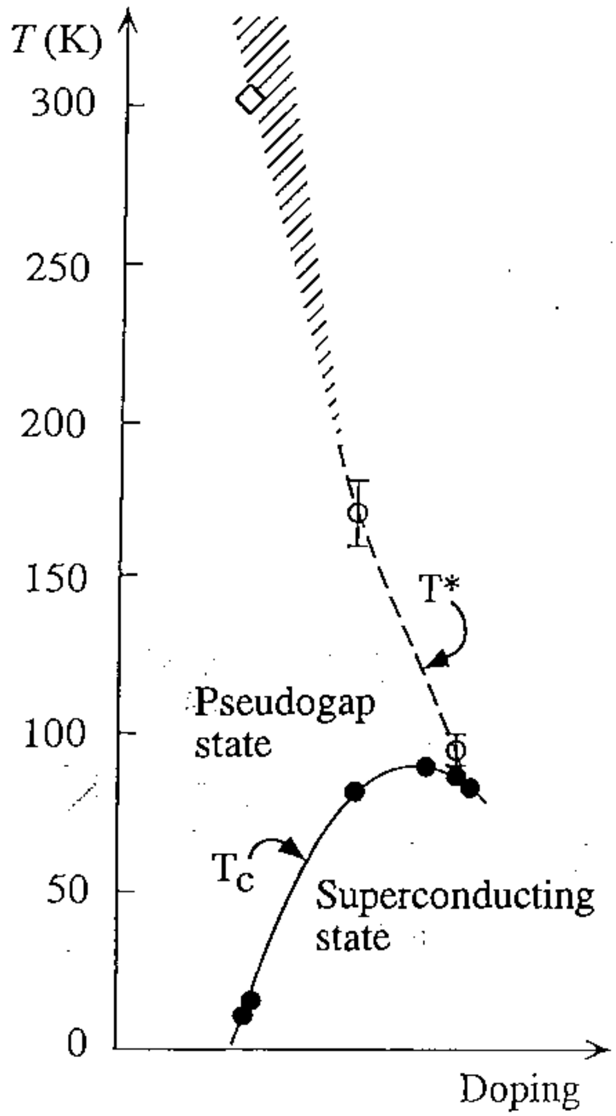


Fig. 7



T (K)
300
250
200
150
100
50
0
T*
Pseudogap
state
Tc
Superconducting
state
Doping

Fig. 8

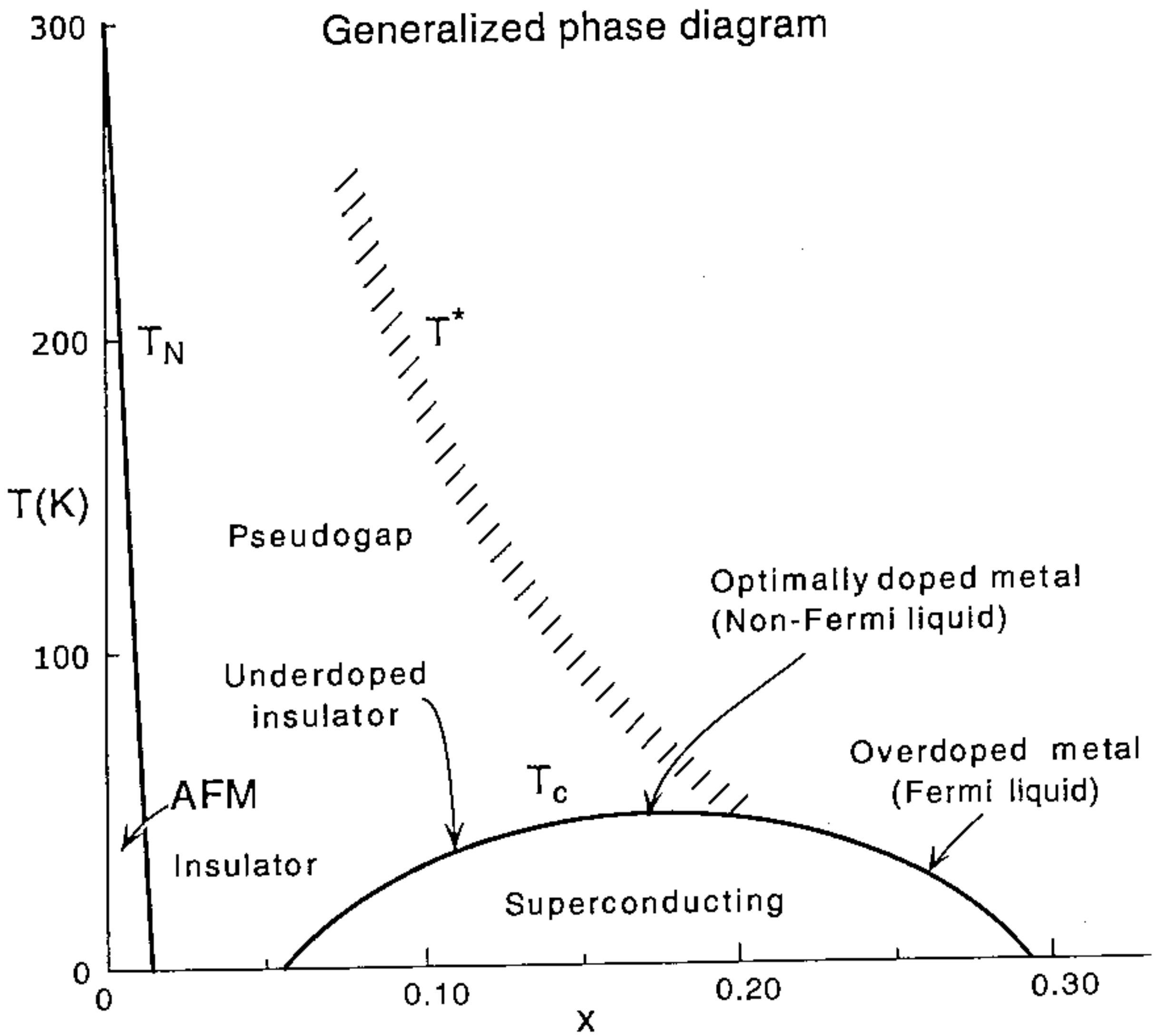

Generalized phase diagram
300
200
100
0
T(K)
T_N
T^*
Pseudogap
Optimally doped metal
(Non-Fermi liquid)
Underdoped
insulator
Overdoped metal
(Fermi liquid)
T_c
AFM
Insulator
Superconducting
0
0.10
0.20
0.30
X

Fig. 9

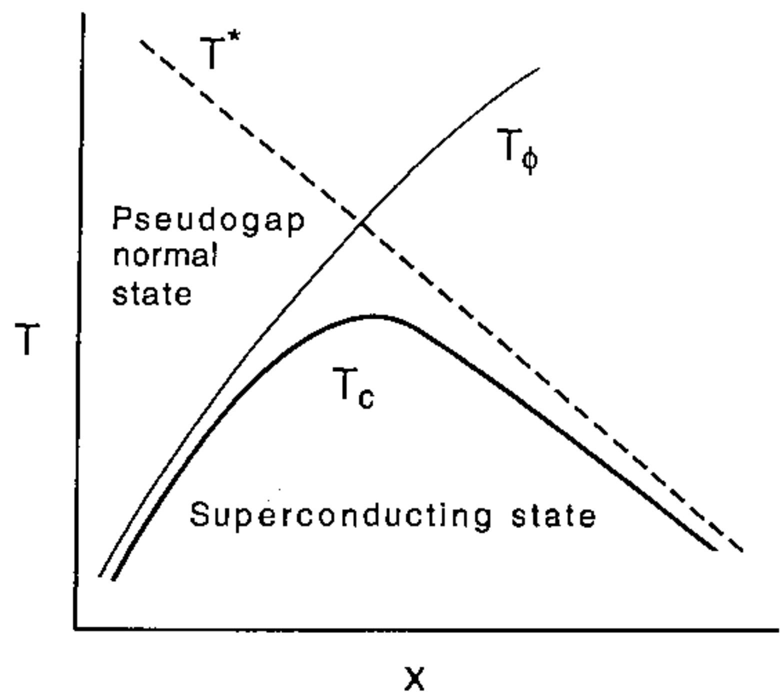


Fig. 10

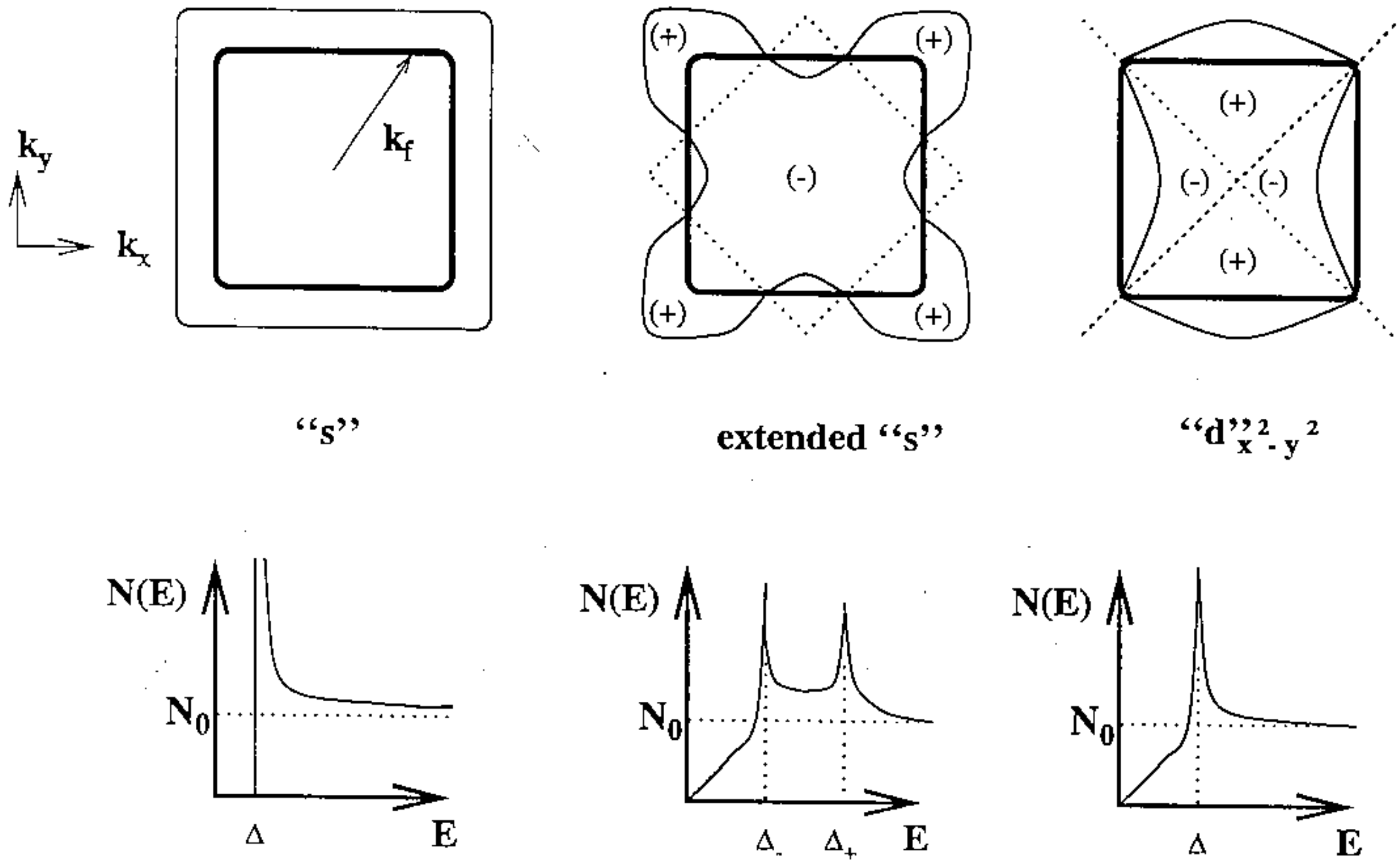
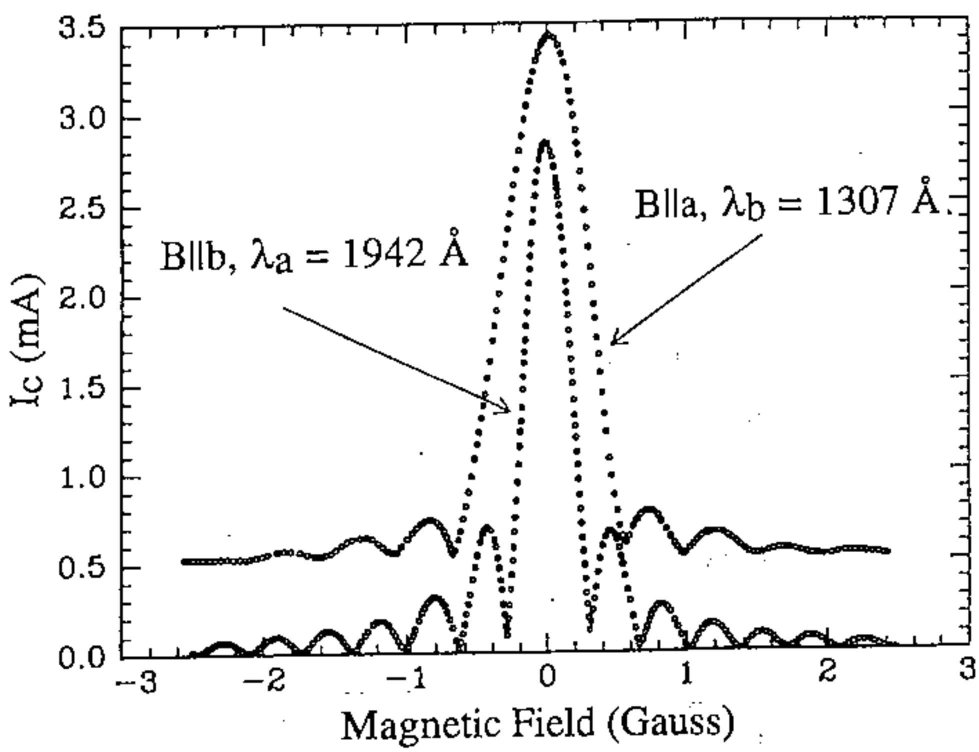
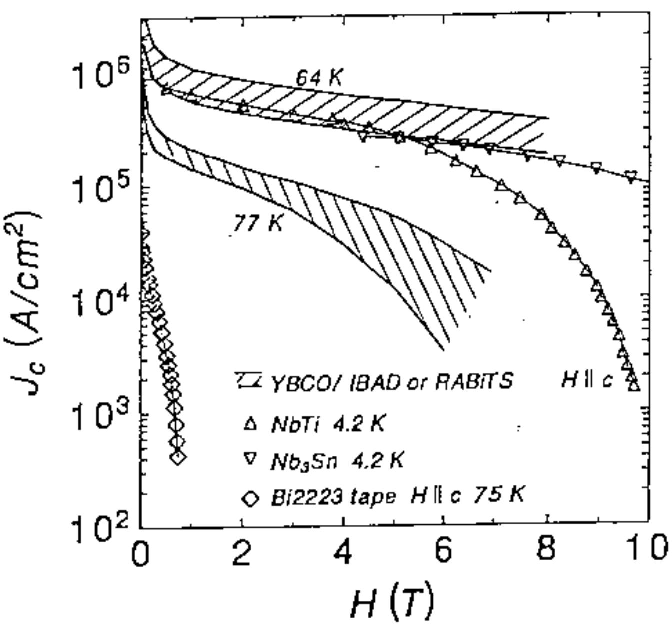


Fig. 11



3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Ic (mA)
−3
−2
−1
0
1
2
3
Magnetic Field (Gauss)
B||b, λa = 1942 Å
B||a, λb = 1307 Å

Fig. 12



64 K
77 K
YBCO/ IBAD or RABiTS
H ∥ c
NbTi 4.2 K
Nb3Sn 4.2 K
Bi2223 tape H ∥ c 75 K
J_c (A/cm²)
10^6
10^5
10^4
10^3
10^2
0
2
4
6
8
10
H (T)

Fig. 13

A possibility of emission of high frequency gravitational radiation from *d*-wave to *s*-wave type superconductor junctions.

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Recent measurements on a class of high-Tc superconductors (HTSC) have shown that Cooper-pairs binding may be associated to a d-wave, while in another class, d and s waves may coexist.

When d-wave Cooper-pairs are injected in a superconductor that can sustain s-wave binding, d-wave pairs decay to s-wave pairs and energy is irradiated by means of gravitons.

We show that in s-wave to d-wave type superconductor (SDS) junctions in an equilibrium condition no net gravitational wave energy is emitted, on the other hand under non equilibrium conditions a net gravitational wave energy is emitted by the junction.

Experiments which show a gravitational interaction between inomogeneus high-Tc superconductors, under non equilibrium conditions, and test objects may be understood by accepting a possibility of emission of gravitational radiation from SDS junctions.

Introduction. In spite of the fact that quantum gravity is a theory currently under development (1), there are few elementary concepts that are involved in the application of some basic ideas related to the quantization of the gravitational field. For istance, it has been demonstrated (2) that gravitational waves, because of their quadrupolar nature, are carried by particles of spin 2, named gravitons. Moreover it has been suggested that atomic transitions for which the quantum number L changes by + or – 2, and for which the total quantum number J changes by 0 or + or – 2 are quadrupolar transitions and are permitted for the emission of gravitons, while the emission of photons is forbidden (2) (3).
Atomic transitions from orbitals 3d to 1s, 3d to 2s and 3d to 3s are possible candidates for transitions which may be applicable for the generation of gravitational radiation by atoms of a suitable material. The material could be pumped by photons and let decay gravitationally. The efficiency of the process depend on the half-lives of metastable states and the possibility of obtaining a population inversion , as we have in LASERs.
While looking for a natural source of high frequency gravitational radiation it has been computed that the energy of gravitons involved in some possible stellar processes are very high, 14.4 keV for ^{57}Fe in the sun and 16.1 MeV from supernovae (2). Halpern's work (2) (3) also defines the gravitational counterpart of the laser, called a "gaser", for which we could prefer the name GWASER, for Gravitational Wave Amplification by Stimulated Emission of Radiation.
In spite of the fact that there is a lack of substantial theoretical and experimental work in this field, we could extend the above mentioned considerations to different quantum systems, looking for a possible candidate to efficient high frequency gravitational wave generators and detectors. Our attention has been focused on superconductors, where the carriers of electric current are bound in atom-like structures composed of two electrons, the Cooper-pairs. Cooper-pairs obey to quantum rules, both individually and collectively. With superconductors we are in the very lucky situation where the collective behaviour may show the individual state of each Cooper pair, being them collectively at the ground state for the specific superconducting material.
Very recently it has been experimentally observed the existence of two different symmetries of the order parameter in high temperature superconductor, a symmetry with an *s*-wave component and a symmetry with a *d*-wave component (5), therefore we know that Cooper-pairs are in *s*-orbitals and *d*-orbitals respectively. We can also predict that when Cooper-pairs move under non equilibrium conditions, i.e. under the effect of magnetic fields, from a superconductor where the symmetry of the order parameter is of type *d* to a superconductor where this symmetry is of type *s*, the Cooper-pairs must decay loosing energy by the emission of gravitons. This working principle is similar to the photon generation mechanism in LEDs and semiconductor injection LASERs, giving the gravitational counterparts that we may call GWEDs and injection GWASERs.

Pairing states in HTSC. The symmetry of the order parameter D (k) in superconductors has been found to have an *s*-wave symmetry in conventional low Tc superconductors and, after an intense research both theoretical and experimental (4) (5) (6) (7), it has been found that YBCO HTSC support both an *s*-wave symmetry and a *d*-wave symmetry depending on the probe direction. The *s*-wave component is due to the distortion by the orthorombic symmetry and it has been found that different HTCS which do not have the orthorombic distortion are nearly pure *d*-

wave (7). A background discussion on the symmetry of pairing states in both conventional and high Tc superconductors can be found in (4). We recall that electron pairing in low Tc superconductors is attributed to phonons, while in HTSC a strong magnetic coupling is believed to cause electron pairing, giving an inevitable *d*-wave symmetry and the high transition temperatures observed.

Emission of gravitational waves from HTSC. The efforts required for the study of the nature of pairing states in HTSC has led to many experiments where Josephson junctions have been prepared using conventional superconductors injecting a supercurrent in HTSC through an insulating barrier. While the obtained interference patterns corroborated the cited theory, we may ask about the angular momentum qauntum number of Cooper-pairs while traversing a *s*-wave to *d*-wave superconductors (SDS) junction. Experiments show that the supercurrent is not destroyed, it follows that each Cooper-pair should emit or absorb a particle carrying a spin of + or - 2, which may be identified with graviton and antigraviton respectively. In a fully superconductive circuit comprising the junction with no current, the number of Cooper-pairs that traverse the junction averages to zero, with no overall emission; on the other hand if a current flows in the superconductor, the distance between *s*-wave to *d*-wave junction and *d*-wave to *s*-wave junction along the current flow can become large enough to create two independent sources of gravitons and antigravitons which are not subjected to a local annihilation, therefore a net emission of gravitational wave could be possible, energy is subtracted from the current loop (flux vortex) which collapses and new loops are created by external fields. It is not known theoretically how much gravitational wave energy could be released by the process, as a complete theory of HTSC has not been fully developed and quantum gravity has only speculative foundations (1), nevertheless we may estimate the order of magnitude of the predicted phenomenon using some well known quantum relations.
We may estimate that the coupling energy that is released by a single decay could be a large fraction of

1) $|Tcp\text{-}Tcs|\ k_B$

where Tcp is the critical temperature of the *p*-wave superconductor and Tcs is the critical temperature of the *s*-wave superconductor and k_B the Boltzmann constant.
If we make the hypotesys that this fraction is a factor of one, we may write:

2) $k_B|Tcp\text{-}Tcs| = hf$

obtaining graviton frequencies of the order of hundreds of GHz.

The maximum power emitted by the process could be found with the hypotesis of currents slightly below the critical currents of most supercondutors, and of about 10 kA/cm_2, obtaining a power density of :

3) $k_B|Tcp\text{-}Tcs|\ (10kA/3.2 \times 10^{-19})\ W/cm^2$

which is of the order of ten W/cm^2.
We observe that the conditions required for the emission of gravitational radiation from a superconductor may have occured incidentally during a sequence of experiments (8) (9) where a dual layered YBCO superconducting disk had been subjected to strong e-m fields. The disk consisted in two layers, the upper part had the orthorombic phase with the c-axis parallel to the surface of the disk and a Tc of 94.2 K, the lower part had a markedly different structure, which was 40 % tetragonal, and Tc equal to 60.5 K. It is not known which was the pairing state of Cooper pairs in the lower part, nevertheles it is supposed to be pure *d*-wave because of the absence of the orthorombic phase. We also observe that the orthorombic layer, because of its orientation supports both *d*-wave and *s*-wave for a supercurrent traversing the junction between the two layers. It follows that a current induced by the complex coil arrangement and traversing the partially SDS junction may have generated a beam of gravitational radiation.
The observed effects were attributed to a possible gravitational shielding; this hypotesis is not corroborated by any currently accepted theory or other supporting experiments, nor the observed region of "interaction", which has exactly the shape of the superconducting disk or toroid for distances of many disk diameters from the device surface, is compatible with a static field modification. On the contrary it is compatible with a beam of millimetric or submillimetric gravitational radiation generated by the decay of Cooper-pairs. The emission is orthogonal to the plane of the junction where small domains should have emitted coherent and thus beamed gravitational radiation, these domains are associated to current fluxes that locally align Cooper-pairs and locally determine the phase of the gravitational wave radiation; we also recall that HTSC are type 2 superconductors which allow the partial penetration of magnetic field by flux vortices.
It has been already shown that gravitational radiation may transfer energy and momentum (10), because of that, the repulsive effect observed in (8) (9) could be a starightforward

consequence of this property of gravitational radiation.

Conclusions. A mechanism for the efficient generation of high frequency gravitational radiation using high Tc superconductors has been proposed and discussed. The mechanism could explain a controversial experiment and clarify its essential features and construction details.
Additional experimental work and theoretical research will be required for a detailed quantitative analysis of the interaction between superconductors and gravitational radiation, nevertheless the possible existence of such a phenomenon will certainly promote the research in this field.

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Gravitation shielding properties of composite bulk $YBa_2Cu_3O_{7-x}$

superconductor below 70 K under electromagnetic field.

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Report MSU-95 chem.

Abstract

High-temperature $YBa_2Cu_3O_{7-x}$ ceramic superconductor with composite structure has revealed shielding properties against gravitational force in the state of levitation at temperatures below 70 K. Bulk ceramic superconductor with a shape of a toroidal disk was prepared using a conventional ceramic technology in combination with melt-texture growth.
Two solenoids were placed around the disk in order to initiate the current inside it and also to provide the rotation around its central axis. The samples placed over the rotating disk demonstrated a weight loss of 0.3-0.5%. When the rotation speed was slowly reduced by electromagnetic field in the solenoids, the shielding effect became considerably higher and reached 1.9-2.1% at maximum.

1. INTRODUCTION

The behavior of high-temperature ceramic superconductors under high-frequency magnetic field and their shielding properties are of great interest for practical application. Crystal structure seems to be the key factor determining all physical properties of bulk superconductors, and the interaction of the structure with the external and internal electro-magnetic fields might result in quite unusual effects. Despite a large number of studies [1-3] the nature of these interactions still remains unresolved. Our recent experimental work [4] clearly indicated that under certain conditions single-phase bulk dense $YBa_2Cu_3O_{7-x}$ revealed a moderate shielding effect against gravitation force.
In order to obtain more information about this unusual phenomenon, a new installation was created which allowed operation with magnetic fields up to 2 T and frequencies up to 10^8 Hz at temperatures from 40 to 70 K. A new experimental technique was applied to modify the structure of the ceramic superconductor. All these efforts yielded a much bigger value in shielding effect (up to 2%) and provided good hopes for industrial application.

2. EXPERIMENTAL

The shielding superconducting element was made of the dense, bulk, almost single-phase $YBa_2Cu_3O_{7-x}$ and had a shape of a toroidal disk with the outer diameter of 275 mm, the inner diameter of 20 mm, and the thickness of 10 mm. The preparation of the 123-compound consisted of mixing the initial oxides followed by calcining the powder at 930 C in air, grinding, pressing the disk at 120 MPa, and sintering it in oxygen at 930 C for 12 h with slow cooling down to room temperature. After that the disk was kept in the furnace at 600 C, and the upper surface was quickly heated to 1200 C using planar high-frequency inductor as shown in Figure 1, with the following cooling down.
During last heating the gap between the sample and the inductor was chosen precisely to provide only the heating of the upper 2 mm-thick layer of the disk, though high heat conductivity of the material caused the heating of some part of the material below this layer. Finally the disk was slowly cooled down to room temperature in a flow of oxygen and treated mechanically in order to obtain good balance during rotation.
Two solenoids were placed around the superconductor as shown in Figure 2. The gaps between these solenoids and the superconductor were big enough so that it could easily move about 20 mm in each direction. The toroidal disk was placed inside a cryostat equipped with a set of three coils which could keep it levitating when it reached the superconducting state. High-frequency electric current was first connected to a couple of two main solenoids around the toroidal disk and thus the current was initiated inside the ceramics. Then the system was cooled by liquid helium vapors to the temperature of 65-70 K and the disk became superconducting. After that the current was sent to the coils below the disk and the superconductor raised up (about 15 mm) because of the Meissner effect.
At this moment small current was sent to the main solenoids and the disk began rotating with increasing speed. The rotation speed was increased up to 5000 rpm. At this moment the measurements of weight for various subjects were taken. Finally the rotation speed was slowly reduced by changing the current in the main solenoids. The speed of rotation was controlled with the help of a laser beam reflected by a small piece of plastic light-reflecting foil attached to the disk.
The measurements of weight were taken constantly during this period too. The frequency of the electromagnetic field was varied from 10^3 to 10^8 Hz. Various materials were used for the measurements of weight over the levitating disk, including metals, glass, plastic, wood and so on. All these samples were placed hanging over the cryostat on a thread connected to sensible balance. The distance from the samples to the cryostat varied from 25 to 1500 mm. The weight of the samples was typically from 10 to 50 grains. Every precaution was taken to avoid all possible disturbances or the induced magnetic field and air flow.
The phase and crystal structure of the superconductor were studied using X-ray diffraction analysis (XRD) and scanning electron microscope (SEM) equipped with energy dispersive spectral (EDS) analyzer. The samples were cut layer by layer from the bulk ceramic disk.
The transition temperature T_c was determined from the resistive transition in a temperature variable cryostat, under zero magnetic field, using an AC current and sputtered golden contacts. The critical current density was measured for the samples cut from the top and from the bottom of the superconducting disk. Je

measurements were carried out at 75 K using an AC current, four-probe method and direct transport measurements.

3. RESULTS

The levitating superconducting ceramic disk revealed clearly visible shielding effect against the gravitational force even without rotation. The values of the weight loss for various samples were within the range of 0.05-0.07%. As soon as the main solenoids were switched on and the disk began rotating in the vapors of liquid helium, the shielding effect increased, and at the speed of 5000 rpm, the air over the cryostat began to raise slowly up to the ceiling. The particles of dust or smoke made the effect clearly visible. The boundaries of the flow could be seen clearly and they corresponded exactly to the shape of the toroid.

The weight of various samples decreased no matter what material they were made of. The samples of the same material but with different masses lost the same fraction of their weight. The loss of weight depended on the shape and the position of the sample. The maximum loss of weight could be reached if the sample was oriented with the flat surface parallel to the surface of the disk, so that the projection of the sample had the maximum area. The best measurement gave the value of the weight loss of 0.5%, while typical values were from 0.3 to 0.5%. The areas close to the inner edge of the toroid (5-7mm from the edge) gave lower values of shielding, from 0.1 to 0.25% only.

During the time when the rotation speed was decreased from 5000 to 3500 rpm using the solenoids as braking tools, the shielding effect reached maximum values and the weight loss of the samples was from 1.9 to 2-1% depending on the position of the sample from the outer edge of the disk. These peak values were measured during 25-30 seconds as the speed decreased rather quickly. Because of considerable vibration of the disk at the rotation speed close to 3000-3300 rpm further braking was done very quickly in order to avoid unbalanced rotation, and the measurements of weight could not be carried out.

The maximum shielding properties were observed for the maximum current inside the superconducting disk. According to preliminary measurements the upper layer of the disk was able of carrying over 15 thousand A/cm^2.

The maximum loss of weight of the samples was observed only at high frequencies of the magnetic field in the interval from 3.2 to 3.8 Mhz, but further detailed investigations are needed as the deviations of weight were sometimes rather large.

In order to prove that the weight loss occurred due to the difference of atmospheric pressure over the cryostat and below it but not as a result of some kind of high frequency field, the air pressure was measured with high precision using mercury barometer. The difference of pressures was clearly observed and was equal to 8mm for the maximum shielding effect.

The analysis of the cross-section of the ceramic $YBa_2Cu_3O_{7-x}$ disk revealed the existence of two different zones of crystal structure. The upper part of the disk (6-7 mm of thickness) had an orthorhombic structure typical for the quench and melt growth process [5,6] and consisted mainly of single-phase orthorhombic 123-compound. The material was dense and had pure and hardly visible grain boundaries. The grains had the size of less than 2 um and were oriented (75%) with c-axis parallel to the surface of the disk. The transition temperature for the material as defined by direct measurements was 94.2 K.

The lower part of the disk which had close contact with water-cooled base during high-frequency heat treatment had a structure with randomly-oriented grains, and the average grain size from 5 to 15 um. The porosity of this zone varied from 5 to 9%. The transition temperature T_c was equal to 65.5 K, and the material contained about 40% of the tetragonal phase.

Crystal lattice parameters for these two layers as calculated from XRD are listed below, the values are given in mm.

upper layer: a=0.381; b=0.387; c=1.165;
lower layer: a=0.384; b=0.388; c=1.170.
a=0.387; c=1.183.

The first (upper) layer was quite homogenous with even distribution of elements in the volume of all the samples. EDS analysis showed the presence of small inclusions of Y_2BaCuO_5 in the lower layer.

4. DISCUSSION

The interaction of a superconducting ceramic body with gravitational field (or with gravitational waves) seems to be a complicated problem and cannot be explained by one law or one physical phenomenon. Common theory of field has little to say about the nature of gravitational field and its interaction with electric, magnetic and nuclear forces. Also an overwhelming explanation of the mechanism of high-temperature superconductivity has not yet been found. Still all these facts do not make the observed phenomenon less interesting.

In our previous work [4] the loss of weight of the sample over the levitating superconductor was extremely small and varied from 0.05 to 0.3%. At that time it was difficult to exclude entirely the influence of radio-frequency field because the sample was separated from the disk and the magnets by a thin plastic film. Now the superconductor was situated in a stainless steel cryostat and the influence of other factors causing the loss of weight should be negligible.

The modification of the crystal structure of a superconductor allowed to obtain a composite body with a dense and oriented upper layer and a porous lower layer with random orientation of the grans. The upper layer is able of carrying high J_c current under considerable magnetic field while the lower layer cannot conduct high currents and is not resistant to the external magnetic field. The lower part of the disk with wide intergrain boundaries is also a source of a great number of Josephson junctions and is responsible for the direct and reverse, primary and secondary Josephson effect. The presence of tetragonal non-superconducting phase allows certain interaction with the external magnetic field.

A combination of two different crystal structures with different behaviour under magnetic field, creates a composite ceramic body with new properties. According to Faraday the replacement of a normal conductor in a magnetic field causes electric current inside it. Usually the magnetic field does not penetrate a superconductor more than a penetration depth, thus the interaction with the field is extremely small. But in the described experiment the superconductor also carries the high frequency electric current modified by Josephson effect. It is possible to admit that some interaction between the composite ceramic body and the external magnetic field takes place. This interaction depends on the coherence length, the flux pinning, the field frequency and the field force, the penetration depth and the parameters of the crystal lattice. These characteristics are interrelated in a complex way.

As analysed in [7] pinning centres with different origins may exist inside the superconducting disk, and fluxes will be trapped at some of them. Fluxes trapped at weak centres will begin to move first and those trapped at strong ones will not move until the Lorentz force exceeds the pinning force. The overall current will be composed of the superposition of the flux motions with different speeds. Generally speaking, the quantized fluxes move as a bundle locally formed in a flux lattice by the magnetic interaction between them.

The temperature is also of great importance as it determines the state of energy inside a superconductor. The shielding effect was observed only below 70 K, while the ceramic disk became superconducting already at 94 K.

A specific state of energy of the superconducting body, caused by the conditions of the experiment, seems to change the behaviour of the whole atomic structure in such a way that the interaction with gravitational field (or waves) becomes different. Then, in order to keep a stable level of energy and a stable atomic and electronic structure, the superconductor absorbs some part of the energy from the gravitational field and slightly decreases it.

Figure 3 gives a schematic diagram of the shielding effect under usual atmospheric pressure (10000 kg/m^2). A thick horizontal line is a superconducting shield which reduces the gravitational force. Every object placed over the superconducting disk will loose only about 2% of its weight, which is not enough to make it levitating. Meanwhile the air over the object will also loose 2% of the weight. The bigger the surface area of the superconductor, the bigger becomes the lifting force. A 2% shielding creates a lifting force of about 200 Kg/m^2 because of the difference of atmospheric pressures under the shield and over it. The shield creates a kind of a vertical tunnel in the air with the reduced gravitational field. The observed effect also works in various gases and liquid media.

Various approaches to the problem of shielding properties of high T_c materials are possible and some of them can be based on the mechanism of superconductivity. All elementary particles are divided by their physical properties into two classes: bosons and fermions. It means that the behaviour of the particles is described by two different quantum statistics: Bose-Einstein or Fermi-Dirac. The electrons of conductivity interact with each other according to Coulomb law and this interaction is strong enough; the binding energy of electrons in metals is comparable with their own kinetic energy, but at low temperatures electrons form sooner liquid than gas. Under vacuum equally charged electrons always undergo repulsion. Inside crystal ionic lattice the energy of the bond of free electrons can be negative and they can attract one another. Electrons with different impulses and spins are able to form pairs, producing one particle with zero spin and zero impulse.

The particles with zero spin obey the statistics of Bose-Einstein. These particles are called bosons and they "tend" to exist in equal quantum state. A good example of bosons properties is Bose-Einstein condensation: at low enough temperature, when kinetic energy of particles is small, they exist at the lowest energy level, revealing new properties. The condensate which is formed from Cooper pairs has no internal friction and demonstrates superfluidity. But superfluidity of a charged liquid is nothing more but superconductivity.

According to BCS theory if we regard weak bond, electrons of conductivity and phonons in the crystal lattice interact from time to time, particles collide but they preserve their individual positions and properties. If we deal with strong bond the interaction takes place all the time and free electrons and phonons exist no longer giving birth to a certain mixture called electron-phonon liquid. This liquid has specific properties and the behaviour of this electron-phonon mixture under various conditions is not yet studied. It is possible to admit that this liquid has some properties similar to those which are typical for magnetic liquids, especially if we take into consideration that magnetic hysteresis is characteristic for high T_c compounds. Also the experimental equipment described above has much in common with magneto-hydro-dynamic (MHD) generator. According to Faraday any conductor moving in the magnetic field produces electric current. The ceramic high T_c disc has a composite structure as it consists of a normal conductor and a superconductor both having good electrical contact. So we can admit that there is a certain interaction of the whole ceramic body with the external magnetic field.

According to the experiment ceramic superconductor kept at the temperature below 70 K does not reveal any unusual shielding if it has no contact with the alternative magnetic field. The shielding effect is extremely small when the sample is levitating over solenoid but has no current inside and is not rotating and has no rotation moment of its own [4]. Only composite structure allows some penetration of the external field inside the body. High-frequency electro-magnetic field provides small wave length and facilitates the interaction with solid body. Various disturbances of the electro-magnetic picture inside the superconductor caused by Josephson junctions do not play any important role, though they should be studied in detail.

There are no grounds to claim that the rotation momentum of the disk interacts with gravitation force, but it seems that fast rotation is favourable for the stabilisation of the shielding effect. The biggest shielding was obtained when the rotation speed was

decreased by magnetic field in the solenoids. The most reasonable explanation at present is that the rotating disk when slowing down is loosing some part of its energy (and of the electron-phonon liquid as well) and in order to compensate [for] the loss of energy, absorbs some part of the energy of gravitation field. Superfluidity of liquid helium at low temperatures is based on the fact that the system tends to loose some energy in order to get a stable energy state. In the observed phenomenon the high T_c system tends to gain some additional energy also in order to keep a stable energy level and stable electronic structure.
The first attempt to a theoretical explanation of the effect has been done by G.Modanese [8]. Further investigations that are in progress, will help to prove or change or to complete the present understanding of the observed phenomenon.

CONCLUSION

A superconducting ceramic levitating disk of $YBa_2Cu_3O_{7-x}$ with composite structure demonstrated stable and clearly visible shielding effect against gravitational force under 70 K and high-frequency electro-magnetic field. A combination of the high-frequency current inside the rotating toroidal disk and the high-frequency external magnetic field created a specific state of energy inside the material. This resulted in the ability of the superconductor to absorb or to modify the energy of the gravitational force and yielded 1.9-2.1% weight loss of the samples.
Various samples made of metals, plastic, ceramic, wood etc. were situated over the disk and their weight was measured with high precision. All the samples showed partial loss of weight no matter what material they were made of. In order to obtain the maximum loss of weight the samples should be oriented with the flat surface parallel to the surface of the disk. The maximum shielding effect (2.1%) was obtained when the speed of the rotation and the corresponding centrifugal force was slightly decreased by the magnetic field.
It was found that gravitation shielding effect depended on the temperature, the speed of rotation, the frequency and the force of the magnetic field. At present it seems a bit early to discuss the mechanisms and to give the detailed analysis of the observed phenomenon as farther investigation is necessary. It is not wise to regard any possibility of anti-gravitation but it seems reasonable to admit that under certain conditions the interaction of solid bodies with electromagnetic and nuclear force fields can demonstrate unusual properties, resulting in specific interaction of the solid substance with gravitational field. The experimentally obtained value of 2% shielding effect might be interesting for scientific and industrial application but no doubt that optimisation of the operation parameters might sufficiently improve the results.

ACKNOWLEDGEMENT

The authors are grateful to the Institute for High Temperatures of the Russian Academy of Sciences for the help in preparation of the unique superconducting ceramic discs and for the possibility to use their technological equipment.

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(5) Murakami M, Morita M, Doi K and Miyamoto K, Jpn.J.Appl.Phys. 28, (1989) 1189.
(6) Murakami M, Morita M and Koyama N, Jpn.J.Appl.Phys. 28, (1989) 1125.
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(8) Giovanni Modanese, electronic preprint MPI-PhT/95-44, hep-th/9505094

3 records selected from **Compendex** for (((anti-gravity) WITHIN ALL))

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3. ☑ **Accession Number:** 6840449
Title: Unidentified flying objects with unusual propulsive techniques: Generation of antigravity by the absorption of gravitational vortices
Author(s): Holwerda, Martin;
First author affiliation: New Energy Foundation ,3318 CG Dordrecht ,Netherlands
Serial Title: Journal of New Energy
Abbreviated Serial Title: J New Energy
Volume:v 6
Issue number: n 1
Issue date: Summer , 2001
ISSN:1086-8259
CODEN: JNENFI
Publication year: 2001
Pages: p 169-178
Abstract: Propulsion and anti-gravity effect of an unidentified flying object (UFO) was discussed. A space liquid model establishing a relation of electrical, gravitational and magnetic phenomena to a concrete flow-pattern of space-liquid was used to explain the studied effects. The pair-formation process and electron-positron annihilation revealed the presence of electrons in the propulsive mechanism of the spacecraft. Gravity was found to be caused due to an excess of anticlockwise spiral-shaped space currents.
Abstract type: (Edited abstract)
Main heading: Spacecraft propulsion
Controlled terms: Gravitational effects; Astrophysics; Positrons; Electrons; Mathematical models
Uncontrolled terms: Unidentified flying objects (UFO); Anti-gravity effects; Positron annihilation
Treatment type: Theoretical;Experimental;
Classification codes: 656.1; 931.5; 657.2; 931.3; 921
Language: English.

Document type: Journal Articles
Database: Compendex

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4. ☑ **Accession Number:** 6840444
Title: The mechanical anti-gravity setups of AG-1, AG-2, AG-3
Author(s): Selin, Alexey;
Serial Title: Journal of New Energy
Abbreviated Serial Title: J New Energy
Volume:v 6
Issue number: n 1
Issue date: Summer , 2001
ISSN:1086-8259
CODEN: JNENFI
Publication year: 2001
Pages: p 128-132
Abstract: Two basic experiments confirm the existence of an energetic aether. One is the bending of light rays from remote stars as reported by A. Eddington in 1919. The second is the observation of the violet frequency shift using the Mossbauer effect as reported by R.V. Pound and G. Rebka in 1961. This paper is a discussion of these observations and the later observations of mechanical means to demonstrate anti-gravity are discussed.
Main heading: Gravitational effects
Controlled terms: Gravitation; Astrophysics; Weightlessness; Hydroelectric generators
Uncontrolled terms: Energetic aether; Mossbauer effects
Treatment type: Theoretical;Experimental;
Classification codes: 931.5; 657.2; 656.1; 611.1; 705.2
Language: English.
Document type: Journal Articles
Database: Compendex

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8. ☑ **Accession Number:** 4
Title: Anti-gravity implies infinite free energy
Author(s): Bass, Robert;
Serial Title: Journal of New Energy
Abbreviated Serial Title: J New Energy
Volume:v 1
Issue number: n 4
Issue date: Winter, 1996
ISSN:1086-8259
Publication year: 1996
Pages: p 76-78
Abstract: If the empirical Podkletnov Effect (Journal of New Energy, vol 2, no 2, ref 4, p 136) is confirmed to be physically valid as described, then it will be simple to produce unlimited free energy from some hitherto untapped renewable source. Indeed, the device described loc.cit. [cf. also Business Week, Sept. 30, 1996, p 42] produces a constant reduction in the measured weight of an arbitrary test mass when run in steady-state at constant power. But this means that the total energy input grows linearly with time, whereas the total energy output stored in a vertically-arrayed flywheel (driven by the torque producible from asymmetric weight-reduction and consequent unbalanced unidirectional torque generated as each successive portion of the flywheel's rim becomes tangent to the Podkletnov beam) grows quadratically with time. The announced result follows at once.
Abstract type: (Author abstract)
Number of references: 4 Refs.
Main heading: Free energy
Controlled terms: Rotating machinery; Flywheels; Calculations; Torque; Energy utilization; Acceleration; Energy storage
Uncontrolled terms: Angular momentum; Rotational kinetic energy
Treatment type: Theoretical;
Classification codes: 641.1; 601.1; 921.6; 931.1; 525.3
Language: English.
Document type: Journal Articles
Database: Compendex

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7 records selected from **Compendex** for (((podkletnov) WITHIN ALL))

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1. ☑ **Accession Number:** 2001025492810
Title: New theoretical approach of the gravitational shielding: Podkletnov's effect
Author(s): Buzea, C.Gh.;Agop, M.;
First author affiliation: Inst of Technical Physics ,Iasi ,Rom
Serial Title: Physica C: Superconductivity and its Applications
Abbreviated Serial Title: Phys C Supercond Appl
Volume:v341-348 (I)
ISSN:0921-4534
CODEN: PHYCE6
Conference Name: International Conference on Materials and Mechanisms of Superconductivity High Temperature Superconductors VI
Conference date: Feb 20-Feb 25 2000
Conference location: Houston, TX, USA
Sponsor: Air Force Office of Scientific Research; Argone National Laboratory; DANKA; ISSO
Conference code: 57787
Publisher: Elsevier Science Publishers B.V., Amsterdam, Netherlands
Publication year: 2000
Pages: p 307-308
Abstract: We show an electromagnetic field can produce a gravitational Meissner effect and, as a result, a gravitational shielding (Podkletnov's effect).
Abstract type: (Author abstract)
Number of references: 7 Refs.
Main heading: Electromagnetic field effects
Controlled terms: Gravitational effects; Maxwell equations; Current density; Electric charge; Light velocity; Permittivity; Magnetic permeability; Superconducting materials
Uncontrolled terms: Gravitational shielding; Podkletnov effect; Gravitational Meissner effect; London equation; Mass density
Treatment type: Theoretical;
Classification codes: 701.2; 701.1; 931.5; 921.2; 741.1; 708.1

Language: English.
Document type: Journal Articles
Database: Compendex

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2. ☑ **Accession Number:** 4
Title: Anti-gravity implies infinite free energy
Author(s): Bass, Robert;
Serial Title: Journal of New Energy
Abbreviated Serial Title: J New Energy
Volume:v 1
Issue number: n 4
Issue date: Winter, 1996
ISSN:1086-8259
Publication year: 1996
Pages: p 76-78
Abstract: If the empirical Podkletnov Effect (Journal of New Energy, vol 2, no 2, ref 4, p 136) is confirmed to be physically valid as described, then it will be simple to produce unlimited free energy from some hitherto untapped renewable source. Indeed, the device described loc.cit. [cf. also Business Week, Sept. 30, 1996, p 42] produces a constant reduction in the measured weight of an arbitrary test mass when run in steady-state at constant power. But this means that the total energy input grows linearly with time, whereas the total energy output stored in a vertically-arrayed flywheel (driven by the torque producible from asymmetric weight-reduction and consequent unbalanced unidirectional torque generated as each successive portion of the flywheel's rim becomes tangent to the Podkletnov beam) grows quadratically with time. The announced result follows at once.
Abstract type: (Author abstract)
Number of references: 4 Refs.
Main heading: Free energy
Controlled terms: Rotating machinery; Flywheels; Calculations; Torque; Energy utilization; Acceleration; Energy storage
Uncontrolled terms: Angular momentum; Rotational kinetic energy
Treatment type: Theoretical;
Classification codes: 641.1; 601.1; 921.6; 931.1; 525.3
Language: English.
Document type: Journal Articles
Database: Compendex

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3. ☑ **Accession Number:** 1
Title: Alternative explanation of 'gravitational screening' experiments
Author(s): de Podesta, Michael;Bull, Martyn;
First author affiliation: Birkbeck Coll ,London ,Engl
Serial Title: Physica C: Superconductivity
Abbreviated Serial Title: Phys C Supercond
Volume:v253
Issue number: n1-2
Issue date: Oct 20, 1995
ISSN:0921-4534
CODEN: PHYCE6
Publisher: Elsevier Science B.V., Amsterdam, Netherlands
Publication year: 1995
Pages: p 199-200
Abstract: We show that the phenomena tentatively ascribed by Podkletnov and Nieminen [Physica C 203 (1992) 441] to gravitational screening may be easily understood in terms of a buoyancy correction to the authors' weighing procedure.
Abstract type: (Author abstract)
Number of references: 2 Refs.
Main heading: Oxide superconductors
Controlled terms: Gravitation; Weighing; Silica; Electric currents; Buoyancy; Cryostats; Calculations; Density (specific gravity); Electric fields
Uncontrolled terms: Gravitational screening; Buoyancy correction; Weight reduction
Treatment type: Experimental;
Classification codes: 708.3.1; 931.5; 943.3; 804.2; 701.1; 931.2
Language: English.
Document type: Journal Articles
Database: Compendex

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4. ☑ **Accession Number:** 1924832

Title: Electroconducting ceramics on the base of cerium, indium oxides and the variation of its properties under the action of different gaseous mediums

Author(s): Akopov, F.A.;Barykin, B.M.;Novov, Yu.D.;Pakhomov, E.P.;Podkletnov, E.E.;

First author affiliation: Inst Vysokikh Temperatur RAN ,Moscow ,Russia

Serial Title: Ogneupory

Abbreviated Serial Title: Ogneupory

Issue number: n 2

Issue date: Feb, 1994

ISSN:0369-7290

CODEN: OGNPA2

Publication year: 1994

Pages: p 10-13

Abstract: High temperature electroconductivity, porosity, compressive and tensile strengthes, thermal stability of ceramics with varying ratio of cerium to indium oxides was studied. Effect of gaseous products of propane combustion on the electroconductivity was examined. N-type conductivity under a such conditions was higher due to the reduction of indium oxide. It was shown that the components of mixed ceramics did not interact.

Number of references: 4 Refs.

Main heading: Ceramic materials

Controlled terms: Refractory materials; Cerium compounds; Indium compounds; High temperature properties; Electric conductivity of solids; Porosity; Thermodynamic stability; Strength of materials; Combustion; Reduction

Uncontrolled terms: Electroconducting ceramics; Propane combustion; N-type conductivity; Mixed ceramics

Treatment type: Experimental;Applications;

Classification codes: 812.1; 812.2; 802.2; 801.4.1

Language: Russian.

Document type: Journal Articles

Database: Compendex

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5. ☑ **Accession Number:** 1502273

Title: Possibility of gravitational force shielding by bulk $YBa_2Cu_3O_{7-x}$ superconductor

Author(s): Podkletnov, E.;Nieminen, R.;

First author affiliation: Tampere Univ of Technology ,Finl

Serial Title: Physica C: Superconductivity

Abbreviated Serial Title: Phys C Supercond

Volume:v 203

Issue number: n 3-4

Issue date: Dec 10, 1992

ISSN:0921-4534

CODEN: PHYCE6

Publication year: 1992

Pages: p 441-444

Abstract: Shielding properties of single-phase dense bulk superconducting ceramics of $YBa_2Cu_3O_{7-x}$ against the gravitational force were studied at temperatures below 77 K. A small non-conducting and non-magnetic sample weighing 5.48 g was placed over a levitating superconducting disk and the loss of weight was measured with high precision using an electro-optical balance system. The sample was found to lose from 0.05 to 0.3% of its weight, depending on the rotation speed of the superconducting disk. Partial loss of weight might be the result of a certain state of energy which exists inside the crystal structure of the superconductor at low temperatures. The unusual state of energy might have changed a regular interaction between electromagnetic, nuclear and gravitational forces inside a solid body and is responsible for the gravity shielding effect.

Abstract type: (Author abstract)

Number of references: 8 Refs

Main heading: High temperature superconductors

Controlled terms: Yttrium compounds; Copper oxides; Ceramic materials; Crystal structure; Electromagnetic shielding; Gravitational effects; Thermal effects; Superconductivity; Magnetic levitation

Uncontrolled terms: Yttrium barium copper oxides; Gravitational force shielding; Levitating superconducting disks; Disk rotation speed; Weight loss; Energy state; Electrooptical balance system

Treatment type: Applications;Experimental;

Classification codes: 708.3.1; 804.2; 812.1; 933.1.1; 701.2; 701.1

Language: English.

Document type: Journal Articles

Database: Compendex

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6. ☑ **Accession Number:** 1171584
Title: Morphology and microstructure of $YBa_2Cu_3O_7$ thin films on $SrTiO_3$ single crystal by RF magnetron sputtering
Author(s): Podkletnov, E.E.;Jaervinen, R.J.O.;Vuorinen, P.T.;Maentylae, T.A.;
First author affiliation: Tampere Univ of Technology ,Finl
Serial Title: Journal of Crystal Growth
Abbreviated Serial Title: J Cryst Growth
Volume:v 114
Issue number: n 1-2
Issue date: Oct, 1991
ISSN:0022-0248
CODEN: JCRGAE
Publication year: 1991
Pages: p 198-202
Abstract: Superconducting thin films of 123 compound were deposited 'in situ' on (100) single crystals of $SrTiO_3$ by RF magnetron sputtering. Oriented films with $T_c(R = 0)$ of 85 K and $J_c = 10^5$ A/cm^2 (at 78 K in zero field) were obtained. In order to provide constant substrate temperature during the deposition and thus to obtain perfect crystal structure, the transparent substrate was coated from the back side by a non-transparent layer of 123 compound before the main 'in situ' sputtering. To reduce the resputtering effect the substrates were placed aside from the projection of the target on the substrate table. Film properties such as crystallinity, surface morphology and composition were analysed by X-ray diffraction (XRD), scanning electron microscopy (SEM) and X-ray energy dispersive spectroscopy (EDS).
Abstract type: (Author abstract)
Number of references: 12 Refs
Main heading: High Temperature Superconductors
Subheading: Thin Films
Controlled terms: Crystals--Growing; Yttrium Compounds; X-Rays--Diffraction; Microscopic Examination--Scanning Electron Microscopy; Ceramic Materials
Uncontrolled terms: Oxide Superconductors; Yttrium Barium Copper Oxides; RF Magnetron Sputtering
Treatment type: Experimental;
Classification codes: 708; 932; 741; 531; 812; 547
Language: English.
Document type: Journal Articles
Database: Compendex

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7. ☑ **Accession Number:** 1042102
Title: Cerium dioxide refractory materials
Author(s): Akopov, F.A.;Romanov, A.I.;Podkletnov, E.E.;Valjano, G.E.;
Monograph Title: Proceedings of the Unified International Technical Conference on
Conference Name: Proceedings of the Unified International Technical Conference on Refractories - UNITECR '89
Conference date: Nov 1-4 1989
Conference location: Anaheim, CA, USA
Conference code: 14079
Publisher: Publ by American Ceramic Soc, Westerville, OH, USA
Publication year: 1989
Pages: p 1071
Document type: Conference Articles
Database: Compendex

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1. ☑ **Accession Number:** 2001025492810
Title: New theoretical approach of the gravitational shielding: Podkletnov's effect
Author(s): Buzea, C.Gh.;Agop, M.;
First author affiliation: Inst of Technical Physics ,Iasi ,Rom
Serial Title: Physica C: Superconductivity and its Applications
Abbreviated Serial Title: Phys C Supercond Appl
Volume:v341-348 (I)
ISSN:0921-4534
CODEN: PHYCE6
Conference Name: International Conference on Materials and Mechanisms of Superconductivity High Temperature Superconductors VI
Conference date: Feb 20-Feb 25 2000
Conference location: Houston, TX, USA
Sponsor: Air Force Office of Scientific Research; Argone National Laboratory; DANKA; ISSO
Conference code: 57787
Publisher: Elsevier Science Publishers B.V., Amsterdam, Netherlands
Publication year: 2000
Pages: p 307-308
Abstract: We show an electromagnetic field can produce a gravitational Meissner effect and, as a result, a gravitational shielding (Podkletnov's effect).
Abstract type: (Author abstract)
Number of references: 7 Refs.
Main heading: Electromagnetic field effects
Controlled terms: Gravitational effects; Maxwell equations; Current density; Electric charge; Light velocity; Permittivity; Magnetic permeability; Superconducting materials
Uncontrolled terms: Gravitational shielding; Podkletnov effect; Gravitational Meissner effect; London equation; Mass density
Treatment type: Theoretical;
Classification codes: 701.2; 701.1; 931.5; 921.2; 741.1; 708.1

Language: English.
Document type: Journal Articles
Database: Compendex

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2. ☑ **Accession Number:** 7
Title: Local gravitoelectromagnetic effects on a superconductor
Author(s): Agop, M.;Buzea, C.Gh.;Nica, P.;
First author affiliation: Technical Univ `Gh. Asachi' ,Iasi ,Rom
Serial Title: Physica C: Superconductivity and its Applications
Abbreviated Serial Title: Phys C Supercond Appl
Volume:v339
Issue number: n2
Issue date: Oct, 2000
ISSN:0921-4534
CODEN: PHYCE6
Publisher: Elsevier Science Publishers B.V., Amsterdam, Netherlands
Publication year: 2000
Pages: p 120-128
Abstract: Maxwell's and London's generalized equations, generalized Meissner effect and gravitational shielding in an electromagnetic field are obtained. In such a context, we show that a neutral particle beam in an infinitely thin superconducting cylinder placed in the Earth's gravitoelectric field is focused, and that the penetration depth increases with the pulsation of the electromagnetic field.
Abstract type: (Author abstract)
Number of references: 25 Refs.
Main heading: Superconducting materials
Controlled terms: Gravitational effects; Electromagnetic dispersion; Maxwell equations; Electromagnetic shielding
Uncontrolled terms: Maxwell-London equations; Meissner effects; Gravitoelectromagnetic effects
Treatment type: Experimental;
Classification codes: 708.3; 931.5; 711.1; 701.1; 701.2; 921.2
Language: English.
Document type: Journal Articles
Database: Compendex

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3. ☑ **Accession Number:** 3443589
Title: Theoretical analysis of a reported weak-gravitational-shielding effect
Author(s): Modanese, G.;
Serial Title: Europhysics Letters
Abbreviated Serial Title: Europhys Lett
Volume:v 35
Issue number: n 6
CODEN: EULEEJ
Publication year: 1996
Pages: p 413
Language: English.
Document type: Journal Articles
Database: Compendex

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4. ☑ **Accession Number:** 2
Title: Does a superconductor shield gravity?
Author(s): Unnikrishnan, C.S.;
First author affiliation: Tata Inst of Fundamental Research ,Bombay ,India
Serial Title: Physica C: Superconductivity
Abbreviated Serial Title: Phys C Supercond
Volume:v266
Issue number: n1-2
Issue date: Jul 20, 1996
ISSN:0921-4534
CODEN: PHYCE6
Publisher: Elsevier Science B.V., Amsterdam, Netherlands
Publication year: 1996
Pages: p 133-137
Abstract: Recently there were some experimental observations which were interpreted as due to

a shielding of the gravitational interaction by a superconducting disc in a static configuration as well as when set in rotation. We examine the experiments in detail and point out some difficulties which should be eliminated before reliable results can be claimed. The data from these experiments provide an internal check on the correctness of the hypothesis and we argue that the observed results are inconsistent with the hypothesis of shielding and therefore they are not due to shielding of the Earth's gravity. Our preliminary experiments in the static case do not show any evidence for the reported shielding.
Abstract type: (Author abstract)
Number of references: 4 Refs.
Main heading: Superconducting materials
Controlled terms: Superconductivity; Magnetic levitation; Gravitational effects
Uncontrolled terms: Meissner effect; Gravitational shielding; Superconductor shield gravity
Treatment type: Experimental;
Classification codes: 708.3; 701.1; 701.2; 931.5
Language: English.
Document type: Journal Articles
Database: Compendex

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Health & Science: Friday, February 27, 1998

Why universe expands? Nature adores a vacuum

by K.C. Cole
Los Angeles Times

In what may be a major insight into the nature of space itself, astronomers have discovered evidence that the universe is expanding rapidly under pressure of an anti-gravity-like force first proposed by Albert Einstein.

While Einstein later called his proposal the worst blunder of his life, his idea has resurfaced over the past decade as a way to solve a host of cosmological conundrums, including suggestions that the universe is younger than some of its stars.

"This is the first believable direct evidence that there might be" such a repulsive force, said astrophysicist Rocky Kolb of Fermi National Accelerator Laboratory in Illinois. "It may have been a blunder for (Einstein) to think it was a blunder."

The discovery was made by an international group of astronomers who looked at exploding stars, or supernovas, that appear to be hurtling away from each other at surprisingly rapid rates.

Astronomers have long known that the universe has continued to expand ever since its explosive birth in the Big Bang. However, it was thought that the mutual gravitational attraction of all the matter and energy in the universe would slow the expansion down. The inward pull of gravity would put a brake on the explosive outward expansion.

These supernovas appeared to be so far away, however, that they imply that the expansion of the universe is actually speeding up, rather than slowing down. It is as if the supernovas were actually picking up speed from some outward pushing force .

"Our observations show that the universe is expanding faster today than yesterday," said University of California, Berkeley, astronomer Adam Riess, one of the scientists who presented the findings at a meeting at UCLA last week. After trying to rule out other explanations, he said, his team proposed the reason might be Einstein's long-abandoned repulsive force.

Anti-gravity it's not, however. Gravity is the mutual attraction of matter and energy. Anti-gravity would imply that matter and energy would somehow mutually repel. If gravity causes two planets to attract each other, anti-gravity would cause them to repel each other.

The repulsive force, however, is the property of empty space itself.

"There's energy in the vacuum of space, and that energy wants to stretch that vacuum," he said. The repulsive force doesn't cause the planets to push away from each other. Rather, it causes the space between them to expand.

"If it's true, it's the craziest thing you could think of," said physicist Lawrence Krauss, of Case Western Reserve University in Cleveland.

Krauss is pleased because he's been proposing for years that Einstein's cosmological constant - the repulsive force - would solve vexing problems. For example, it would resolve the possible contradiction between the age of the universe and the oldest stars.

The problem would be solved by a universe that is expanding more rapidly today than yesterday, because such a universe would be older than a steadily expanding universe.

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Pitt physicist offers spin on a universal theory

Beyond the rim of mainstream physics, a professor offers his ideas on matter and the nature of the universe

Monday, April 06, 1998

By Byron Spice, Science Editor, Post-Gazette

Astrophysicists are abuzz this spring over observations of distant exploding stars that suggest the expansion of the universe is picking up speed.

It's a new twist on an old question: Will the expansion of the universe that began in the Big Bang 15 billion years ago continue forever, eventually stop under the tug of gravity, or even reverse itself in a Big Crunch?


Physicist Ernest Sternglass (Bill Wade Post-Gazette)

Evidence that the expansion actually is accelerating, first announced in January by an international team of astronomers, is still preliminary and hotly debated. But it raises the intriguing possibility that some strange force may be at work - some sort of anti-gravity, or what Albert Einstein called the cosmological constant.

Physicist Ernest Sternglass, on the other hand, offers his own spin - literally - to the question. The universe, he suggests, is not only expanding but rotating. If the expansion is accelerating, it's due to nothing more than plain old centrifugal force.

"It's just inertial force," said Sternglass, 74, an emeritus professor of radiological physics at the University of Pittsburgh, "the same kind of force that keeps the moon from falling down." It's the same force that makes his grandchildren hold on tight as they twirl on a park merry-go-round.

The rotating universe will continue to expand until the force of gravity balances the inertial forces, resulting in a stable cosmos.

This view, which Sternglass explains in his book, "Before the Big Bang," published late last year by Four Walls Eight Windows, is consistent with the predictions of Immanuel Kant, the 18th-century German philosopher. But it is well outside the mainstream of contemporary physics.

Likewise, Sternglass' theory that the negatively charged electron and its oppositely charged twin, the positron, are the fundamental building blocks of the universe flies in the face of the standard model of particle physics.

"I'm very skeptical," said Allen Janis, a theoretical physicist at Pitt who has ruminated and argued with his friend Sternglass for four decades. "He's a very imaginative person ... but I'm not convinced ... There is a coherent, well-verified body of knowledge and this just doesn't fit with that at all."

Sternglass is accustomed to life outside the mainstream. It was Einstein, he says, who encouraged him to pursue his physics theories outside of academia while earning a living in applied science. Though his work at Westinghouse Research Laboratories led to development of the video camera tube that captured Neil Armstrong's first steps on the moon and to ultraviolet-light detectors used in orbiting telescopes, his outspoken concerns about the dangers of radioactive fallout and nuclear power plant emissions made him a controversial figure in the 1960s and '70s.

He says he is satisfied with his accomplishments and has no regrets about the choices he has made in his life and career. And he retains the enthusiasm of a young boy.

"When I look in the mirror," he said, "I cannot believe I'm as old as I am."

A meeting with Einstein

It was a decidedly fresh-faced Sternglass who uneasily rang the doorbell at Einstein's house in Princeton, N.J., one cool spring day in 1947.

Newly hired by the Naval Ordnance Laboratory, Sternglass had been asked to explore the possibility of developing a night vision system. He had some ideas for building a television camera that could detect infrared light and he had written to Einstein in hopes of discussing them with the great physicist.

Dressed in a baggy gray gym suit, Einstein showed Sternglass to the back porch. What Sternglass expected to be a brief discussion turned into a five-hour conversation. Einstein and Sternglass, who had immigrated from Berlin with his physician parents in 1938, chatted in German about the nature of light particles called photons, about Einstein's dislike for quantum mechanics and his frustration with trying to develop a unified theory that would explain all of the forces of the universe.

"I found him to be very depressed and very sad," Sternglass recalled. Einstein was upset that he had made little progress on his unified field theory, his wife had died, and his son suffered from mental illness. "Here was this man so widely admired and respected ... yet he felt a failure."

What most confounded Sternglass was Einstein's career advice. Sternglass was considering going back to school for an advanced degree in physics. Einstein advised him to pursue physics on his own and, perhaps most importantly, always have "a cobbler's job."

"Don't do what I have done," Sternglass, in his book, quotes Einstein as saying. He made a mistake, he told Sternglass, when he left his job as a patent examiner for a position with the University of Berlin. He had no real duties at the university, Einstein explained: "Nothing to do except wake up and solve the problems of the universe every morning. Nobody can do that."

Sternglass decided to return to Cornell University for graduate studies, eventually earning his doctorate, but he followed Einstein's advice in seeking a "cobbler's job." In 1952, he moved to Pittsburgh to join the Westinghouse lab. There, he could continue his studies in electron scattering and a phenomenon known as secondary electron emission, which interested Westinghouse because of its potential use in building electronic X-ray image intensifiers.

In 1967, he joined the Pitt Medical School's radiology department, where he investigated electronic techniques that would permit lower doses of diagnostic X-rays and applied computer techniques to enhance diagnostic images.

Earning and learning

While these jobs put food on the table, Sternglass pursued his interest in physics on the side. As Einstein had predicted, this arrangement allowed him to pursue far-out ideas and make his mistakes in private.

In 1963, Sternglass' work gained him a brief moment of fame. At a meeting of the American Physical Society in New York City, he outlined his theory on the nature of matter. He argued that all matter is composed of electrons and positrons.

Later that year, however, Murray Gell-Mann and George Zweig of the California Institute of Technology developed a theory of quarks, fractionally charged subatomic particles that comprise the protons and neutrons of atomic nuclei. Sternglass' theory was soon forgotten.

He would gain much more fame -- or infamy -- for his opposition to nuclear power. He argued that even low levels of nuclear fallout and radioactive emissions from nuclear power plants could damage children, raising infant mortality rates and depressing Scholastic Aptitude Test scores.

The vast majority of scientists rejected these notions. Neither Westinghouse nor Pitt ever tried to muzzle him, but Sternglass knows that his stands isolated him within the scientific community.

"Many of my former friends were very upset," he said.

His own interest in electrons and positrons was revived in 1974 when physicists at Brookhaven National Laboratory and the Stanford Linear Accelerator Center discovered a particle they called the J/Psi meson. It was both an unusually dense and unusually long-lived particle and it got Sternglass wondering about the nature of the "primeval atom."

The primeval atom was a concept developed by Georges Lamaitre, a Belgian priest and astrophysicist, in the 1920s. He envisioned the universe being created by the breakup of this primeval atom, an idea that presaged the Big Bang theory.

Sternglass saw this primeval atom as an electron-positron pair. This pair of particles rapidly orbited each other and contained all of the mass of the universe.

In a series of steps beginning billions of years before the Big Bang, this electron-positron pair went through a series of splits, creating thousands of electron-positron "seed pairs" from which galaxies later would emerge.

By contrast, according to the standard model of particle physics, the universe was condensed into an infinitely dense point before the Big Bang.

Sternglass said his model and the standard model don't differ markedly in terms of how elementary particles were formed in the minutes following the Big Bang.

Astrophysicists have long worried that the universe behaves as if it has much more mass than humans can see. Sternglass suggests some of this "missing mass" may be in the form of seed pairs that did not expand immediately after the Big Bang and remain sprinkled through the universe.

A universe in ether

In addition to suggesting that the universe is rotating, Sternglass resurrects the 3,000-year-old notion of the universe existing within an "ether," a liquid-like medium. Scientists once considered ether essential. For instance, scientists who observed light behaving like a wave reasoned that light would have to move through some sort of medium if it was to make waves.

But Einstein's photoelectric theory dispensed with the need for ether. He showed that light behaved as a particle, a photon. His theory of relativity also dispensed with ether, by showing that the speed of light need not be measured relative to an ether.

In Sternglass' view, matter exists as circular vortices -- something like a smoke ring -- moving through an ether. Just as air is capable of uprooting trees and tossing cars when whipped into a tornado, these vortices transform energy into mass, he said.

No one has ever been able to prove that ether exists, Sternglass acknowledged, but that doesn't necessarily mean it doesn't.

"There are fashions in science just as there are fashions in art," he added. Ether is clearly out of fashion.

Fashions do exist, "but that's a double-edged sword," said Adolf Grunbaum, the Andrew Mellon Professor of philosophy of science at Pitt.

"The mere fact of the existence of fashions in science does not show, in a given case, that an unorthodox point of view is necessarily soundly supported by the evidence."

If most physicists aren't ready to embrace Sternglass' view, they might have trouble dismissing it, admitted Pitt's Janis. "As far as specific predictions he makes, there is nothing at the moment that could convincingly demonstrate that his ideas are wrong."

One important piece of evidence might come once a new particle accelerator, called the Large Hadron Collider, is completed at the European Laboratory for Particle Physics, or CERN, near Geneva, Switzerland. Scientists say the machine might produce a particle called the Higgs; if this particle is proven to exist, scientists believe it will confirm much of the standard model. Sternglass' theory predicts no such particle exists.

In the meantime, Sten Odenwald, an astronomer who works under contract with Goddard Space Flight Center in Greenbelt, Md., and runs the popular Astronomy Cafe Web site, said evidence from the Cosmic Background Explorer satellite in the early 1990s suggests the universe is not rotating, or at least not rotating much.

And even the recent evidence of possible acceleration of the universe's expansion may be questionable, Odenwald said. Those findings come from observing just a handful of exploding stars called supernovae. More observations could alter those findings dramatically.

Sternglass is realistic about his chances of convincing other physicists.

"Let's face it: When I present these things at astronomical meetings, it's a 10-minute presentation and people don't know what to make of it," he said.

"Nobody may believe me until after I'm dead," but that's OK, he added. "You have to take the long view."

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Nation & World: Friday, January 23, 1998

Warped idea? NASA grasps for the stars

by Robert S. Boyd
Knight Ridder Newspapers

WASHINGTON - Not content with exploring our dinky little solar system, NASA is studying ways to travel across trillions of miles of empty space to the stars - first by robots, ultimately perhaps by humans.

NASA Administrator Daniel Goldin says he hopes the space agency will be able to launch an interstellar spaceship within the next 25 years and to reach an alien planet around a nearby star by the end of the 21st century, when today's children's children will be alive.

"We're going to want to send spacecraft toward distant worlds," Goldin told the American Astronomical Society here. "It sounds a little far out, but we've come a long way already. We can get there with a robotic explorer in a few generations."

As a preliminary step, Goldin has directed NASA's Jet Propulsion Laboratory in Pasadena, Calif., which managed the spectacular Mars Pathfinder landing last summer, to develop plans for an "interstellar precursor mission" - perhaps using exotic technology such as sails powered by light, or anti-gravity, warp drives or wormholes.

Goldin said NASA is not expecting short-term practical benefits from interstellar travel, but rather sees it as a logical continuation of humanity's age-old itch to explore. Furthermore, he believes researchers should push beyond the frontiers of existing technology.

Even enthusiasts agree that star travel won't be easy. Landing on the moon or Mars is a stroll on the beach compared with the difficulties of reaching even the nearest star, Alpha Centauri, 24 trillion miles away.

The basic problem is distance. If the sun were the size of a tennis ball, Pluto would be 100 yards away, but 600 lonesome miles would lie between Earth and Alpha Centauri. The star's light, traveling at 186,281 miles per second, takes more than four years to reach the Earth.

The current distance record for a spacecraft - 6.3 billion miles - is held by NASA's Pioneer 10, which was launched 26 years ago and is coasting away from the sun at 27,000 miles per hour. At that rate, it would take 100,000 years to get to Alpha Centauri.

So, fundamental breakthroughs in physics, chemistry and biology would be required. Today's chemical-fueled rockets don't have enough oomph.

Last year, NASA sponsored a workshop in Cleveland on exotic space-propulsion systems; 84 government, university and industrial scientists and engineers plotted how to break the universal speed limit.

"Imagine it," said Catherine Asaro, a physicist in Greenbelt, Md., who attended. "NASA invites you to an invitation-only conference, sits you down at a table with some of the best minds in physics, and says, `OK, figure out how to go faster than the speed of light!' "

According to Einstein's theory of relativity, an object cannot exceed the speed of light.

But science is constantly doing things once thought impossible, such as cloning an adult sheep, creating anti-matter or recovering the DNA of a Neanderthal man.

"One should never say `never' in science," Floyd Bloom, editor of the respected journal Science, wrote last month. "Barriers that are acceptable by today's logic could eventually yield to persistent research."

One technique discussed at the Cleveland conference is to somehow warp, or bend, the fabric of space-time to shorten the distance between Earth and a star. A rough analogy would be folding a piece of paper to connect two points that used to be separated. Such a shortcut through space is known as a wormhole.

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PHYSICA C

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A New Theoretical Approach of the Gravitational Shielding: Podkletnov's Effect

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We show an electromagnetic field can produce a gravitational Meissner effect and, as a result, a gravitational shielding (Podkletnov's effect).

1. INTRODUCTION

Gravitational Meissner effect can not be found in usual matter. Consequently, gravitational shielding does not occur here. However, particular space-time structures like wormholes [1] or cosmic strings [2], which violate the null energy condition (NEC theorem), might reveal such peculiar features [3].

In this paper we show that the presence of an electromagnetic field can cause a gravitational Meissner effect and, as a result, a gravitational shielding.

2. GENERALIZED MAXWELL AND LONDON EQUATIONS

It is well known that Einstein's field equations in the weak field approximation and at low speeds reduce to Maxwell's type equations [4]. Then, by superposition, the generalized Maxwell equations (of the electromagnetic and gravitational field) become :

$$\begin{aligned}
&\nabla\cdot\mathbf{g}=\left(-4\pi G+\frac{1}{\varepsilon_0}\frac{q^2}{m^2}\right)\rho\\
&\nabla\cdot\mathbf{B}=0\\
&\nabla\times\mathbf{g}=-\frac{\partial\mathbf{B}}{\partial t}\\
&\nabla\times\mathbf{B}=\left(-\frac{4\pi G}{c^2}+\mu_0\frac{q^2}{m^2}\right)\mathbf{j}+c^{-2}\frac{\partial\mathbf{g}}{\partial t}
\end{aligned}\tag{1}$$

where the following substitutions have been used :

$$\mathbf{g}=\mathbf{g}_g+\frac{q}{m}\mathbf{g}_e,\quad \mathbf{B}=\mathbf{B}_g+\frac{q}{m}\mathbf{B}_e,\qquad \rho_e=\frac{q}{m}\rho,\quad \mathbf{j}_e=\frac{q}{m}\mathbf{j}\tag{2}$$

In relations (1) and (2) ($\mathbf{g}_e$, $\mathbf{B}_e$) are the electromagnetic field components, ($\mathbf{g}_g$, $\mathbf{B}_g$) the gravitational field components, $\mathbf{j}_e$ the electric field current density, $\mathbf{j}$ the mass current density, ρ_e the electric charge density, ρ the mass density, q the electric charge of a particle, m its mass, G is Newton's constant, c the speed of light, ε_0 the electric permitivity and μ_0 the magnetic permeability.

If the wave function $\psi=|\psi|e^{i\varphi}$ is minimally coupled to the generalized vector potential $\mathbf{A}=\mathbf{A}_g+(q/m)\,\mathbf{A}_e$, the mass current density $\mathbf{j}$ is

$$\begin{aligned}
\mathbf{j}=m\mathbf{j}_p&=\frac{\hbar}{2i}\left(\psi^*\overline{\nabla}\psi-\psi\overline{\nabla}\psi^*\right)=\\
&=\frac{\hbar}{2i}\left(\psi^*\nabla\psi-\psi\nabla\psi^*\right)-\hbar g\mathbf{A}|\psi|^2
\end{aligned}\tag{3}$$

where $\mathbf{j}_p$ is the probability current density, $\overline{\nabla}=\nabla-ig\mathbf{A}$ the covariant derivative, $\mathbf{A}_g$ the gravitoelectromagnetic vector potential, $\mathbf{A}_e$ the electromagnetic vector potential, g a coupling constant, q and m the charge and the mass of the superconducting pair, respectively. For $n=|\psi|^2=$ constant and $g=m/\hbar$, the curl of relation (3) leads to the second London equation

$$\mathbf{B}=-\frac{1}{\rho}\nabla\times\mathbf{j},\tag{4}$$

The first generalized London equation results from the third eq. (1) and eq. (4) using the standard procedure [5]

$$\mathbf{g}=\frac{1}{\rho}\frac{\partial\mathbf{j}}{\partial t}\tag{5}$$

Under these circumstances "matter" satisfying generalized London equations (4) and (5) defines a generalized superconductor. The electrono-positronic vacuum, type I and II superconductors are only few examples of generalized superconductors.

3. GENERALIZED MEISSNER EFFECT AND GRAVITATIONAL SHIELDING

Let us consider the last eq. (1) where we neglect the electromagnetic $\partial_t\mathbf{g}_e$ and gravitational $\partial_t\mathbf{g}_g$ displacement currents. Using the substitutions $\lambda_e=\left(m\mu_{0e}^{-1}q^{-2}n^{-1}\right)^{1/2}$ and $\lambda_g=\left(\mu_{0g}^{-1}m^{-1}n^{-1}\right)^{1/2}$ with

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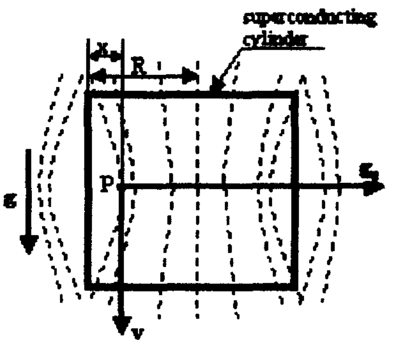

Figure 1 Change of the lines of the gravitational field **g** close to a cylinder coated with high temperature superconductors.

$\mu_{0g} = 4\pi G c^{-2}$, the curl of this equation with (4) becomes

$$\Delta \mathbf{B} - \left(\lambda_e^{-2} - \lambda_g^{-2}\right)\mathbf{B} = 0 \qquad (6)$$

Equation (6) argues that for $\lambda_g > \lambda_e$, i.e. $q/m > (\mu_{0g}/\mu_{0e})^{1/2} = 4.25 \cdot 10^{-11}$ C/m, a generalized Meissner effect might occur in generalized superconductors. In this context the parameter $\lambda = \lambda_g \lambda_e \left(\lambda_g^2 - \lambda_e^2\right)^{-1/2}$ corresponds to the generalized penetration depth. It is easy to test such an effect may occur in conventional superconductors. Consequently, for $m=9.1 \cdot 10^{-31}$ kg, $q = 1.6 \cdot 10^{-19}$ C, $n = 10^{28}$ m^{-3}, $\lambda_e \approx 10^{-8}$ m and $\lambda_g \approx 10^{13}$ m and (6) becomes

$$\Delta \mathbf{B} - \lambda_e^{-2}\mathbf{B} \approx 0 \qquad (7)$$

For $\lambda_g < \lambda_e$, i.e. $q/m < (\mu_{0g}/\mu_{0e})^{1/2} = 4.25 \cdot 10^{-11}$ C/m, eq. (6) indicates that in a generalized superconductor, the generalized Meissner effect is not present, in other words, the field **B** induces in superconductor spatial oscillations with the wavelength $\lambda' = \lambda_g \lambda_e \left(\lambda_e^2 - \lambda_g^2\right)^{-1/2}$.

Now, following the same method used in [5] one finds for the component g the equation

$$\Delta \mathbf{g} - \left(\lambda_e^{-2} - \lambda_g^{-2}\right)\mathbf{g} = 0 \qquad (8)$$

Therefore, for $\lambda_g > \lambda_e$ the lines of the field **g** are expelled from the superconductor, in other words, having in view its structure, it is possible to shield the gravitational field by means of an electromagnetic field. Such a shielding effect is present in Podkletnov's effect : a sample body placed over a spinning superconducting disk looses its weight [6].

In such a context, a superconducting cylinder placed in the gravitational field of the Earth will act as a particle focusing device. Indeed, any particle moving along this cylinder with the speed v is subjected to a force (see figure 1)

$$g_g = g_0 \exp\left(-\frac{R-x}{\lambda_e}\right), \qquad (9)$$

solution of eq. (8).

Then for $(R-x)/\lambda_e \ll 1$ the particle's equation of motion becomes, on a first approximation

$$\ddot{y} + \omega^2 y = 0, \quad y = R - x, \quad \omega^2 = g_0 \lambda_e^{-1} \qquad (10)$$

Under these circumstances, taking into account results from refs. [7] the focusing length is

$$f = 2\pi v \omega^{-1} \qquad (11)$$

E.g., for a beam of ultracold neutrons with speed $v \sim 10^{-2}$ m/s moving inside a cylinder coated with HTS, the focusing length calculated with (11) is $f \sim 1$ cm.

4. CONCLUSIONS

The main conclusions of the present work are as follows :

- assuming the superposition principle as valid we get Maxwell type equations for the generalized field (electromagnetic plus linear gravitational);
- we get the generalized London equations;
- we establish the conditions necessary for the generalized Meissner effect to occur;
- we show that if an electromagnetic field is present, the gravitational shielding is possible to appear; in our opinion, this way Podkletnov's effect may be seen and understood [6];
- we propose a new experiment of focusing a beam of ultracold neutrons by a superconducting cylinder with its generatrix aligned parallel to the lines of the Earth's gravitational field.

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PHYSICA C

Alternative explanation of "gravitational screening" experiments

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Abstract

We show that the phenomena tentatively ascribed by Podkletnov and Nieminen [Physica C 203 (1992) 441] to gravitational screening may be easily understood in terms of a buoyancy correction to the authors' weighing procedure.

Podkletnov and Nieminen [1] report that they have observed phenomena consistent with gravitational screening by a bulk superconductor. Their experiments consist of weighing a sample of SiO_2 above a liquid helium cryostat containing samples of YBCO superconductor. They report apparent reductions in sample weight from that observed at room temperature varying between 0.05% with no AC current in the superconductor to around 0.5% with AC currents flowing in the superconductor. Our assumptions concerning their apparatus are illustrated in Fig. 1 of their paper, reproduced here.

However, the authors have made no correction for the buoyancy of their SiO_2 samples in the air in which they are weighed. A simple calculation shows that the downward force which is counteracted by the weighing apparatus is given by

$$F = \rho_{\text{Sample}} V g - \rho_{\text{Gas}} V g \qquad (1)$$

Assuming a density of 2100 kg m^{-3} for the SiO_2 and that the atmosphere within the cryostat is air, we have calculated the ratio of the density of air within the cryostat to the density of the SiO_2 sample. By assuming that the density of air is similar to that of dry nitrogen [2], we predict an apparent weight loss of a similar magnitude to that observed (Fig. 2).

What this amounts to is an explanation of the phenomenon observed in terms of the *temperature* of the gas around the sample. In the steady state (no rotating fields) the sample is reported to show weight reduction of 0.05%, which indicates a sample temperature of the order of 150 K. When AC fields are in place, convection within the cryostat may reduce this temperature significantly, thus increasing the density of the gas. The convection would not need to exert a force on the sample directly but would merely lower the temperature of the air surrounding the sample. The convection could be driven by slight

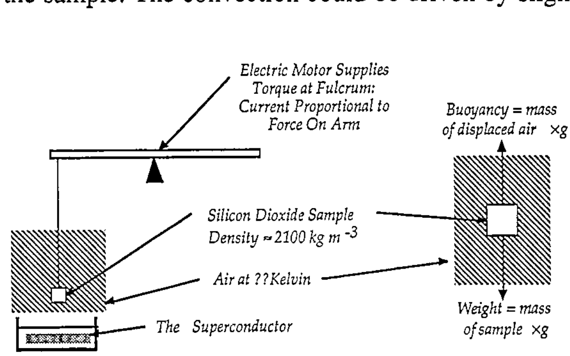

Fig. 1. Schematic of the experimental apparatus described by the authors.

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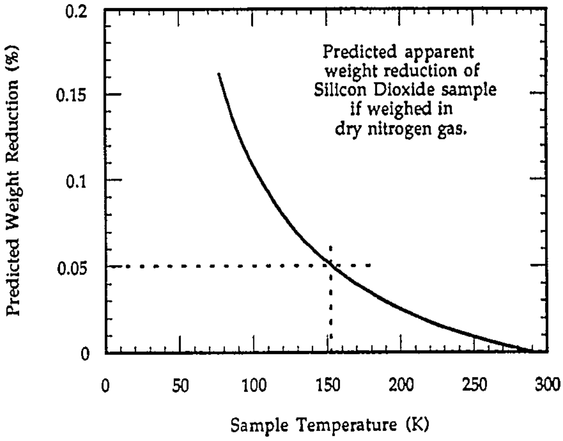

Fig. 2. Prediction of the percentage reduction in apparent sample weight of an SiO_2 sample compared with its apparent weight at 290 K. The data assumes that the sample is weighed in dry nitrogen gas at atmospheric pressure, but the results are likely to be similar for dry air.

heating of the cryostat walls. This suggestion is directly falsifiable by measurement of the time variation of the temperature in the region of the sample. Note that the calculations reported in Fig. 2 are based on the density of dry nitrogen.

While the matter of a buoyancy correction in a weighing experiment is not of itself particularly important, the interpretation of the results that the authors have suggested is of great significance. We thus feel that it is important to ascertain that there are no alternative explanations for these observations before accepting the possibility of gravitational shielding.

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Local gravitoelectromagnetic effects on a superconductor

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Abstract

Maxwell's and London's generalized equations, generalized Meissner effect and gravitational shielding in an electromagnetic field are obtained. In such a context, we show that a neutral particle beam in an infinitely thin superconducting cylinder placed in the Earth's gravitoelectric field is focused, and that the penetration depth increases with the pulsation of the electromagnetic field. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Maxwell's and London's generalized equations; Generalized Meissner effect; Gravitational shielding in an electromagnetic field; Dispersion relations for superconductors

1. Introduction

Several experiments have been proposed to detect local gravitoelectromagnetic effect [1], but the practical difficulties are high. One of the reasons for studying the extreme sensitivity of superconducting devices may enable one to test gravitational effects. De Witt [2] and Anandan [3] studied gravitomagnetic effects on a superconducting circular ring. From the flux quantization condition, they calculated the magnetic field inside a superconducting ring, which is induced by an applied gravitomagnetic field. Papini [4] studied gravitomagnetic effects on a Josephson interferometer and designed an experiment to test the Machian principle. Cerdonio [5] discussed two kinds of detectors for the local gravitomagnetic effect of the Earth, one of them based on the London momentum phenomenon. Recently, Podkletnov and Nieminen experimentally showed that a superconducting disk under electromagnetic field behaves as a gravitational shield [6].

In this paper, we propose an approach of studying gravitoelectromagnetic effects on superconductors. Assuming the gravitational and electromagnetic field superposition principle as valid, we obtain the generalized Maxwell's equation, and from here, on minimal coupling basis, the generalized London's equations. In such a context, we study the generalized Meissner effect and then, the gravitational shielding in an electromagnetic field. We build the solution of differential equations corresponding to the gravitational shielding effect for an infinitely thin superconducting cylinder placed in the Earth's gravitoelectric field. From this solution, we show that a neutral particle beam has cnoidal oscillation modes. By degeneration, we obtain harmonic, soliton, soliton packet modes. Since for the harmonic mode the beam is focused,

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we suggest an experimental test. Using a dispersion relation, we show that the penetration depth increases with the pulsation of the electromagnetic field.

2. Generalized Maxwell equations

When four-dimensional space–time is split into space plus time $(3+1)$, the electromagnetic field $F^{\alpha\beta}$ breaks up into two parts, the electric field $\boldsymbol{g}_{\mathrm{e}}$ and the magnetic field $\boldsymbol{B}_{\mathrm{e}}$. These fields verify Maxwell's equations:

$$\nabla \cdot \boldsymbol{g}_{\mathrm{e}} = \frac{\rho_{\mathrm{e}}}{\varepsilon_0}, \tag{1}$$

$$\nabla \cdot \boldsymbol{B}_{\mathrm{e}} = 0, \tag{2}$$

$$\nabla \times \boldsymbol{g}_{\mathrm{e}} = -\frac{\partial \boldsymbol{B}_{\mathrm{e}}}{\partial t}, \tag{3}$$

$$\nabla \times \boldsymbol{B}_{\mathrm{e}} = \mu_0 \boldsymbol{j}_{\mathrm{e}} + c^{-2}\frac{\partial \boldsymbol{g}_{\mathrm{e}}}{\partial t}, \tag{4}$$

where $\boldsymbol{j}_{\mathrm{e}}$ is the electric current density vector $\boldsymbol{j}_{\mathrm{e}} = \rho_{\mathrm{e}}\boldsymbol{v}$, ρ_{e} the electric charge density, μ_0 the vacuum magnetic permeability and c the speed of light in vacuum. Similarly, the general relativistic gravitational field $(g^{\alpha\beta})$ breaks into three parts [7]: (i) an electric like part, g^{00}, whose gradient for weak gravity is Newtonian acceleration $\boldsymbol{g}_{\mathrm{g}}$; (ii) a magnetic part, g^{0i}, whose curl for weak gravity is the gravitomagnetic field $\boldsymbol{B}_{\mathrm{g}}$; (iii) a spatial metric, g^{ij}, whose curvature tensor is the 'curvature of space' [8].

Although in astrophysics some theories of quasar and galactic nuclei rely on the gravitomagnetic field of a supermassive black hole for energy storage, power generation, jet formation and jet alignment, experiments have only probed g^{00} and g^{ij} with less than 0.1% accuracy. The gravitomagnetic potential g^{0i} is so weak in the Solar system that it has never been detected. According to the magnetic-type gravitation theory [9], in a two-body system, say, the moon–earth system, the body moving on the orbit produces a gravitomagnetic field $\boldsymbol{B}_{\mathrm{g}}$ at the center of the orbit. $\boldsymbol{B}_{\mathrm{g}}$ makes the rotation axis of the central body precess. An experiment, which seems sufficiently feasible, is the gravitomagnetic-induced precession, relative to the star, of a superconducting gyroscope in an earth-orbiting satellite [10].

The relativistic weak-field approximation is constructed beginning from the axiom of relativity that the local coordinates, covering some patch on the space–time manifold which forms an open neighborhood about the origin, in terms of which the metric is Minkovskian up to first order in the coordinate over this patch. This construction may be carried out everywhere on the manifold [11].

In the weak gravitational field, we assume the metric in the form [12]

$$g_{\mu\nu} \approx \eta_{\mu\nu} + h_{\mu\nu} = \eta_{\mu\nu} + \bar{h}_{\mu\nu} - \tfrac{1}{2}\eta_{\mu\nu}\bar{h},$$

where $\eta_{\mu\nu} = (+,-1,-1,-1)$ is the usual Minkovski metric, $h_{\mu\nu}$ is to be treated as a small perturbation to $\eta_{\mu\nu}$, and

$$h_{\mu\nu} = \bar{h}_{\mu\nu} - \tfrac{1}{2}\eta_{\mu\nu}\bar{h}, \quad \bar{h} = h^{\alpha}_{\alpha}.$$

The contravariant form of the metric to first order is

$$g^{\mu\nu} \approx \eta^{\mu\nu} - h^{\mu\nu}, \quad h^{\mu\nu} = \eta^{\mu\alpha}\eta^{\nu\beta}h_{\alpha\beta},$$

and the determinant of the contravariant metric

$$g = \det(g_{\mu\nu}) \approx -1 - h, \quad (-g)^{1/2} = 1 + \frac{h}{2},$$
$$h = h^{\alpha}_{,\alpha}.$$

Since all the covariant derivatives reduce to partial derivatives,

$$\nabla_\mu h_{\alpha\beta} \approx \partial_\mu h_{\alpha\beta},$$

the Riemann tensor, $R^{\sigma}_{\mu\nu\lambda}$, and the Ricci tensor $R_{\mu\nu}$ become

$$R^{\sigma}_{\mu\lambda\nu} = \partial_\nu \Gamma^{\sigma}_{\mu\lambda} - \cdots$$
$$\approx \tfrac{1}{2}\left(\partial^\sigma\partial_\lambda h_{\mu\nu} + \partial_\mu\partial_\nu h^{\sigma}_{\lambda} - \partial_\mu\partial_\lambda h^{\sigma}_{\nu} - \partial_\nu\partial^\sigma h_{\lambda\mu}\right),$$

and

$$R_{\mu\nu} = R^{\lambda}_{\mu\lambda\nu} \approx \tfrac{1}{2}\left(\partial^\lambda\partial_\lambda h_{\mu\nu} + \partial_\mu\partial_\nu h - \partial_\mu\partial_\lambda h^{\lambda}_{\nu} - \partial_\nu\partial^\lambda h_{\lambda\mu}\right),$$

respectively.

We introduce the tensor

$$G^{\mu\nu\lambda} = \tfrac{1}{2}\left(\bar{h}^{\mu[\nu,\lambda]} + \eta^{\mu[\nu}\bar{h}^{\lambda]\alpha}_{,\alpha}\right) \tag{5}$$

so that with the gauge condition,

$$\begin{aligned}&\partial_\mu\left[g^{\mu\nu}(-g)^{1/2}\right]=0,\\&\quad\partial_\mu h^{\mu\nu}\equiv\partial_\mu h^{\mu\nu}_{,\mu}\cong\tfrac{1}{2}\partial^\nu h,\ \ \bar{h}^{\mu\nu}_{,\mu}=0,\end{aligned}\tag{6}$$

Einstein's equations reduce to

$$G^{\mu\nu\lambda}_{,\lambda}=-\frac{8\pi G}{c^4}T^{\mu\nu},\tag{7}$$

where G is Newton's constant and $T^{\mu\nu}$ is the energy–momentum tensor that is the source of the gravitational field. From Eqs. (5) and (6), we get

$$\begin{aligned}&G^{\mu\nu\lambda}=-G^{\mu\lambda\nu},\quad G^{\mu\nu\lambda}+G^{\nu\lambda\mu}+G^{\lambda\mu\nu}=0,\\&\quad G^{\alpha\mu\nu,\lambda}+G^{\alpha\nu\lambda,\mu}+G^{\alpha\lambda\mu,\nu}=0.\end{aligned}\tag{8}$$

As in the case of usual Maxwell's equations, since we do not require a completely covariant formulation, it is convenient to break the tensors into scalar, vector and tensor parts according to the transformation properties under pure rotations.

We introduce the vectors

$$\begin{aligned}&\boldsymbol{g}_{\rm g}=\left(g^1_{\rm g},g^2_{\rm g},g^3_{\rm g}\right),\qquad g^i_{\rm g}=G^{00i}\ \ (i=1,2,3),\\&\boldsymbol{A}_{\rm g}=\left(A^1_{\rm g},A^2_{\rm g},A^3_{\rm g}\right),\quad A^i_{\rm g}=\tfrac{1}{4}h^{0i}\\&\boldsymbol{B}_{\rm g}=\left(B^1_{\rm g},B^2_{\rm g},B^3_{\rm g}\right),\quad B^1_{\rm g}=G^{023},\quad B^2_{\rm g}=G^{031},\\&\quad B^3_{\rm g}=G^{012}.\end{aligned}\tag{9}$$

Substituting Eq. (9) into Eq. (5), we find

$$G^{0ij}=A^{i,j}_{\rm g}-A^{j,i}_{\rm g},\qquad \boldsymbol{B}_{\rm g}=\nabla\times\boldsymbol{A}_{\rm g}.\tag{10}$$

Using Eqs. (9) and (10), from Eqs. (7) and (8), we get the Maxwell-type gravitational equations for the weak gravitational field:

$$\nabla\cdot\boldsymbol{g}_{\rm g}=-4\pi G\rho,\tag{11}$$

$$\nabla\cdot\boldsymbol{B}_{\rm g}=0,\tag{12}$$

$$\nabla\times\boldsymbol{g}_{\rm g}=-\frac{\partial\boldsymbol{B}_{\rm g}}{\partial t},\tag{13}$$

$$\nabla\times\boldsymbol{B}_{\rm g}=-\frac{4\pi G}{c^2}\boldsymbol{j}+\frac{1}{c^2}\frac{\partial\boldsymbol{g}_{\rm g}}{\partial t},\tag{14}$$

where $\boldsymbol{j}$ is the mass current density vector, $\boldsymbol{j}=\rho\boldsymbol{v}$ and ρ, the mass density. This form of the decomposed equations is valid in any coordinate system. They are covariant under transformations of the spatial coordinates $\bar{x}^i=\bar{x}^i(x^1,x^2,x^3)$, but it should be stressed that, in general, once a particular coordinates system is chosen, the equations cannot be taken simply over another system of coordinates by an arbitrary coordinate transformation of the type $\bar{x}^\alpha=\bar{x}^\alpha(x^0,x^1,x^2,x^3)$. It is necessary to return to the original term of the decomposed equations and substitute the quantities appropriate to the new system of coordinates.

Quantitatively, the linearizing approximation is extremely well justified on the surface of any member of our Solar system. Even on the surface of a white dwarf, the deviation of g_{00} from unity does not exceed a value of the order of 10^{-5}. Therefore, we can postulate, ab initio, the Maxwell-type gravitational equations for linear gravitation.

Now, if in a space–time manifold, Eqs. (1)–(4) as well as Eqs. (11)–(14) are valid, based on the superposition principle, we can introduce the generalized fields:

$$\boldsymbol{g}=\boldsymbol{g}_{\rm g}+\frac{q}{m}\boldsymbol{g}_{\rm e},\qquad \boldsymbol{B}=\boldsymbol{B}_{\rm g}+\frac{q}{m}\boldsymbol{B}_{\rm e}.\tag{15}$$

These fields verify the generalized Maxwell's equations

$$\nabla\cdot\boldsymbol{g}=\left(-4\pi G+\frac{1}{\varepsilon_0}\frac{q^2}{m^2}\right)\rho,\tag{16}$$

$$\nabla\cdot\boldsymbol{B}=0,\tag{17}$$

$$\nabla\times\boldsymbol{g}=-\frac{\partial\boldsymbol{B}}{\partial t},\tag{18}$$

$$\nabla\times\boldsymbol{B}=\left(-\frac{4\pi G}{c^2}+\mu_0\frac{q^2}{m^2}\right)\boldsymbol{j}+\frac{1}{c^2}\frac{\partial\boldsymbol{g}}{\partial t},\tag{19}$$

where we accounted for the following relations:

$$\rho_{\rm e}=\frac{q}{m}\rho,\qquad j_{\rm e}=\frac{q}{m}j.\tag{20}$$

As an example, Eq. (16) is obtained adding Eq. (1) multiplied by q/m to Eq. (11) and taking into account the first relation in Eqs. (15) and (20), respectively.

3. Generalized London equations

If the wave function $\psi = |\psi| e^{i\varphi}$ is minimally coupled to the generalized vector potential

$$\boldsymbol{A} = \boldsymbol{A}_g + \frac{q}{m}\boldsymbol{A}_e, \tag{21}$$

the mass current density $\boldsymbol{j}$ is

$$\begin{aligned}\boldsymbol{j} = m\boldsymbol{j}_p &= \frac{\hbar}{2i}\left(\psi^*\bar{\nabla}\psi - \psi\bar{\nabla}\psi^*\right) \\ &= \frac{\hbar}{2i}(\psi^*\nabla\psi - \psi\nabla\psi^*) - \hbar g\boldsymbol{A}|\psi|^2,\end{aligned} \tag{22}$$

where $\boldsymbol{j}_p$ is the probability current density, $\bar{\nabla} = \nabla - ig\boldsymbol{A}$ the covariant derivative, $\boldsymbol{A}_g$ the gravito-electromagnetic vector potential, $\boldsymbol{A}_e$ the electromagnetic vector potential, g a coupling constant, q and m the effective charge and the effective mass of the superconducting pair, respectively.

For $n = |\psi|^2 =$ constant, relation (22) becomes

$$\boldsymbol{j} = \hbar|\psi|^2(\nabla\varphi - g\boldsymbol{A}), \tag{23}$$

or with $g = m/\hbar$ and taking the curl,

$$\boldsymbol{B} = -\frac{1}{\rho}\nabla\times\boldsymbol{j}, \tag{24}$$

where the following notations have been used:

$$\begin{aligned}\boldsymbol{B} &= \nabla\times\boldsymbol{A}, & \boldsymbol{B}_g &= \nabla\times\boldsymbol{A}_g, \\ \boldsymbol{B}_e &= \nabla\times\boldsymbol{A}_e, & \rho &= m|\psi|^2,\end{aligned} \tag{25}$$

We refer to Eq. (24) as the second generalized London equation. This relation embodies some particular interesting cases. They read as follows:

(i) For $\boldsymbol{B}_g = 0$ and

$$\lambda_e = \left(\frac{m}{\mu_{0e}q^2 n}\right)^{1/2}, \tag{26}$$

Eq. (24) reduces to the second London equation [13]

$$\boldsymbol{B}_e = -\mu_{0e}\lambda_e^2\nabla\times\boldsymbol{j}_e, \tag{27}$$

where λ_e is the electromagnetic penetration depth.

(ii) For $\boldsymbol{B}_e = 0$ and

$$\lambda_g = \left(\frac{1}{\mu_{0g}nm}\right)^{1/2}, \quad \mu_{0g} = \frac{4\pi G}{c^2}, \tag{28}$$

Eq. (24) reduces to the second gravitational London equation

$$\boldsymbol{B}_g = -\mu_{0g}\lambda_g^2\nabla\times\boldsymbol{j}, \tag{29}$$

where μ_{0g} defines the "gravitational permeability of vacuum" and λ_g the "gravitational penetration depth" [14].

Let us write Eq. (18) in the form

$$\nabla\times\left(\boldsymbol{g} + \frac{\partial\boldsymbol{A}}{\partial t}\right) = 0. \tag{30}$$

Integrating results in

$$\boldsymbol{g} + \frac{\partial\boldsymbol{A}}{\partial t} = 0. \tag{31}$$

Since from Eq. (24), one gets

$$\boldsymbol{A} = -\frac{1}{\rho}\boldsymbol{j}, \tag{32}$$

substituting the time derivative from this relation in Eq. (31), the first generalized London equation results

$$\boldsymbol{g} = \frac{1}{\rho}\frac{\partial\boldsymbol{j}}{\partial t}. \tag{33}$$

This relation embodies some particular interesting cases. They read as follows:

(i) For $\boldsymbol{g}_g = 0$ and using substitutions (26), relation (33) reduces to the first London equation [13]

$$\boldsymbol{g}_e = \mu_{0e}\lambda_e^2\frac{\partial\boldsymbol{j}_e}{\partial t}. \tag{34}$$

(ii) For $\boldsymbol{g}_e = 0$ and using substitutions (28), relation (33) reduces to the first gravitational London equation [14]

$$\boldsymbol{g}_g = \mu_{0g}\lambda_g^2\frac{\partial\boldsymbol{j}}{\partial t}. \tag{35}$$

Under these circumstances, "matter" satisfying generalized London equations (24) and (33) defines a generalized superconductor. The electrono-positronic vacuum, type I and II superconductors are only few examples of generalized superconductors.

4. Generalized Meissner effect

Let us consider Eq. (19) wherein we neglect the electromagnetic $\partial_t \boldsymbol{g}_e$ and gravitational $\partial_t \boldsymbol{g}_e$ displacement currents. With substitutions (26) and (28) and applying the curl it becomes

$$\Delta \boldsymbol{B} - \left(\frac{1}{\lambda_e^2} - \frac{1}{\lambda_g^2}\right)\boldsymbol{B} = 0, \tag{36}$$

where we took into account Eq. (17). Eq. (36) argues that for $\lambda_g > \lambda_e$, i.e. $q/m > (\mu_{0g}/\mu_{0e})^{1/2}$, a generalized Meissner effect might occur in generalized superconductors. In this context the parameter $\lambda = \lambda_g \lambda_e (\lambda_g^2 - \lambda_e^2)^{-1/2}$ corresponds to the generalized penetration depth.

It is easy to test that such an effect may occur in conventional superconductors. Consequently, for $\lambda_e \approx 10^{-8}$ m [13] and $\lambda_g \approx 10^{13}$ m [14] and Eq. (36) becomes

$$\Delta \boldsymbol{B} - \frac{1}{\lambda_e^2}\boldsymbol{B} \approx 0. \tag{37}$$

For $\lambda_g < \lambda_e$, i.e. $q/m < (\mu_{0g}/\mu_{0e})^{1/2}$, Eq. (36) indicates that in a generalized superconductor, the generalized Meissner effect is not present, in other words, the field B induces, in superconductor, spatial oscillations with the wavelength $\lambda' = \lambda_g \lambda_e (\lambda_e^2 - \lambda_g^2)^{-1/2}$.

Eq. (36) embodies some interesting cases. Thus,

(i) For $\boldsymbol{B}_g = 0$, Eq. (36) becomes Eq. [13]

$$\Delta \boldsymbol{B}_e - \frac{1}{\lambda_e^2}\boldsymbol{B}_e = 0 \tag{38}$$

namely, the usual Meissner effect;

(ii) For $\boldsymbol{B}_e = 0$, Eq. (36) becomes

$$\Delta \boldsymbol{B}_g + \frac{1}{\lambda_g^2}\boldsymbol{B}_g = 0, \tag{39}$$

namely, the gravitational Meissner effect is absent [15]. These results are different compared with those obtained by Peng in Ref. [16]. Thus, from Ref. [16] and with notations (26) and (28) we obtain

$$\Delta \boldsymbol{B} - \left(\frac{1}{\lambda_e^2} + \frac{1}{\lambda_g^2}\right)\boldsymbol{B} = 0.$$

From here, for the gravitational field, it gives the gravitational Meissner effect:

$$\Delta \boldsymbol{B} - \frac{1}{\lambda_g^2}\boldsymbol{B} = 0.$$

This relation is not in agreement with Refs. [15,17,18]. In the references, mentioned we showed that the gravitational Meissner effect is not present in a pure gravitomagnetic field. The absence of the effect was interpreted as a self-structuring of the physical space–time in a boundless crystal named "world crystal".

5. Generalized shielding

Substituting Eq. (24) into Eq. (19) and taking into account notations (26) and (28), it gives

$$\Delta \boldsymbol{j} - \nabla(\nabla \cdot \boldsymbol{j}) - \left(\frac{1}{\lambda_e^2} - \frac{1}{\lambda_g^2}\right)\boldsymbol{j} = 0. \tag{40}$$

Since the conservation law

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \boldsymbol{j} = 0 \tag{41}$$

with $\rho =$ constant implies

$$\nabla \cdot \boldsymbol{j} = 0, \tag{42}$$

Eq. (40) becomes

$$\Delta \boldsymbol{j} - \left(\frac{1}{\lambda_e^2} - \frac{1}{\lambda_g^2}\right)\boldsymbol{j} = 0. \tag{43}$$

From here, differentiating with t and taking into account Eq. (31), we get

$$\Delta \boldsymbol{g} - \left(\frac{1}{\lambda_e^2} - \frac{1}{\lambda_g^2}\right)\boldsymbol{g} = 0. \tag{44}$$

Therefore, for $\lambda_g > \lambda_e$, the lines of the field $\boldsymbol{g}$ are expelled from the superconductor; in other words, having its structure in view, it is possible to shield the gravitational field by means of an electromagnetic field. Podkletnov and Nieminen experimentally verified this effect in Ref. [6].

6. Oscillation modes in thin cylindrical superconductors

For a superconductor in the Earth's gravitoelectric field, Eq. (44) takes the form

$$\Delta g_{\mathrm{g}} - \frac{1}{\lambda_{\mathrm{e}}^2} g_{\mathrm{g}} = 0. \tag{45}$$

In the case of an infinitely thin superconductor cylinder of radius R (Fig. 1), the solution of Eq. (45) (see the method from Ref. [19]), i.e.

$$g_{\mathrm{g}}(x) = g_0 \mathrm{e}^{-(R-x)/\lambda_{\mathrm{e}}}, \quad x \leqslant R, \tag{46}$$

where g_0 is the gravitoelectric field on the cylinder's surface, (from Eq. (46) $x = R$ corresponds to the cylinder's surface), indicates that on a particle moving with speed v, acts the specific repulsive force:

$$\frac{\mathrm{d}^2 x}{\mathrm{d}t^2} = -g_{\mathrm{g}}(x). \tag{47}$$

Consequently, a beam placed near the superconductor cylinder axis is focused. Let us consider the dimensionless differential equation (47) assuming $y = R - x/\lambda_{\mathrm{e}} \ll 1$, i.e.,

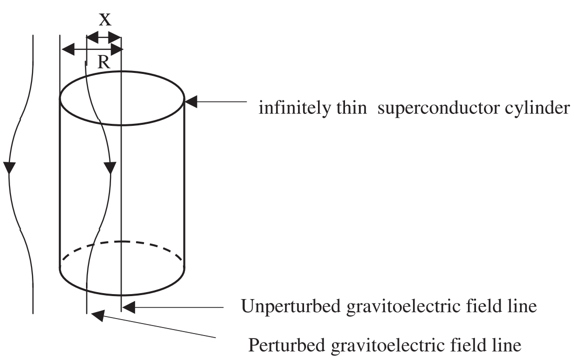

Fig. 1. Thin superconducting cylinder in a gravitoelectric field.

$$\frac{\mathrm{d}^2 y}{\mathrm{d}\tau^2} = \frac{g_0}{\lambda_{\mathrm{e}}\omega^2}\left(\frac{y^2}{2} - y + 1\right), \quad \tau = \omega t. \tag{48}$$

Integrating twice, results in

$$\left(\frac{\mathrm{d}y}{\mathrm{d}\tau}\right)^2 = \frac{g_0}{3\lambda_{\mathrm{e}}\omega^2} P(y), \tag{49}$$

and, respectively,

$$\int \frac{\mathrm{d}u}{[(1-u^2)(1-k^2u^2)]} = \gamma \int \mathrm{d}\tau, \tag{50}$$

where we used the substitutions,

$$\begin{aligned} &y = e_1 + (e_2 - e_1)u^2, \qquad A = \frac{e_2 - e_1}{2}, \\ &k^2 = \frac{e_2 - e_1}{e_3 - e_1}, \qquad \gamma^2 = \frac{g_0(e_3 - e_1)}{12\lambda_{\mathrm{e}}\omega^2}, \end{aligned} \tag{51}$$

$$\begin{aligned} P(y) &= y^3 - 3y^2 + 6y + 6C \\ &= (y - e_1)(y - e_2)(y - e_3), \\ C &= \text{const.} \end{aligned} \tag{52}$$

with $e_1 < e_2 < e_3$, the real roots of the polynomial $P(y)$. Finally, using the method given in Ref. [20], the solution becomes

$$y = e_2 - 2Acn^2[\gamma(\tau - \tau_0); k], \tag{53}$$

where cn is Jacobi's elliptic function with modulus k [20]. Thus, the oscillation modes of a particle beam, which travels parallel and near the cylinder axis, are cnoidal (Fig. 2) and have the following particularities:

(i) The period

$$T = 2\left(\frac{6\lambda_{\mathrm{e}}}{g_0 A}\right)^{1/2} K(k)k. \tag{54}$$

This result is obtained by integrating Eq. (39) with substitution $u = \sin\varphi$ in the limits 0 and $\pi/2$ and taking into account that $cn^2(\theta + 2K) = cn^2(\theta)$, i.e.,

$$\begin{aligned} 2K(k) &= 2\int_0^{\pi/2} \frac{\mathrm{d}\varphi}{(1 - k^2\sin^2\varphi)^{1/2}} \\ &= \frac{1}{k}\left(\frac{g_0 A}{6\lambda_{\mathrm{e}}}\right)^{1/2} \int_0^T \mathrm{d}t. \end{aligned} \tag{55}$$

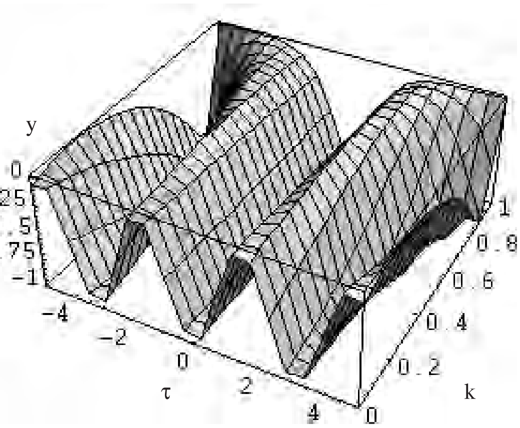

Fig. 2. Cnoidal oscillation modes.

(ii) The mean elongation

$$\bar{y} = -\frac{2A}{k^2}\frac{E(k)}{K(k)} + e_3, \tag{56}$$

where

$$E(k) = \int_0^{\pi/2} (1 - k^2 \sin^2\varphi)^{1/2} \mathrm{d}\varphi. \tag{57}$$

This result is obtained using the averaging relation

$$\bar{y} = \frac{1}{T}\int_0^T y(t)\mathrm{d}t. \tag{58}$$

Under these conditions, the focusing distance for a particle beam of speed v has the form

$$f = \frac{\lambda}{4} = \frac{1}{2}\left(\frac{6\lambda_e}{g_0 A}\right)^{1/2} vK(k)k. \tag{59}$$

By specifying the modulus k, we distinguish the following degenerations:

(i) For $k = 0$, Eq. (53) reduces to the harmonic mode

$$y = e_1 - A\cos\omega t \tag{60}$$

relative to $\bar{y} = e_1$ with pulsation

$$\omega = \left(\frac{g_0}{\lambda_e}\right)^{1/2}. \tag{61}$$

Then, the focusing distance becomes

$$f = \frac{v\pi}{2}\left(\frac{\lambda_e}{g_0}\right)^{1/2}. \tag{62}$$

(ii) For $k \to 0$, Eq. (53) reduces to the harmonic modes packet

$$y \to e_1 - A\left[\cos\omega t + \tfrac{1}{8}k^2\cos 2\omega t + \mathrm{O}(k^4)\right] \tag{63}$$

relative to $\bar{y} \to e_1$, with pulsation

$$\frac{2g_0 A}{3\lambda_e \omega^2} \to k^2\left(1 + \frac{k^2}{2}\right) + \mathrm{O}(k^6). \tag{64}$$

Then, the focusing distance becomes

$$f \to \frac{v\pi}{2}\left(\frac{3\lambda_e}{2g_0 A}\right)^{1/2} k\left(1 + \frac{k^2}{4}\right) + \mathrm{O}(k^5). \tag{65}$$

(iii) For $k = 1$, Eq. (53) reduces to the 'solitonic' mode

$$y = e_3 - \frac{a}{\mathrm{ch}^2\left[\left(\frac{g_0 a}{12\lambda_e}\right)^{1/2} t\right]} \tag{66}$$

relatively to $\bar{y} = e_3$, with amplitude $a = e_2 - e_1$ and 'width' $D = (12\lambda_e/g_0 a)^{1/2}$. Since the pulsation is infinite, see relation (54) for $K(1) = \infty$, the focusing distance is infinite.

(iv) For $k \to 1$, Eq. (53) reduces to a 'solitonic' modes packet relative to $\bar{y} = e_3$, with pulsation

$$\omega \to \frac{2\pi}{\left(\frac{6\lambda_e}{g_0 A}\right)^{1/2} \ln\left(\frac{16}{1-k^2}\right)}. \tag{67}$$

Then, the focusing distance becomes

$$f \to \frac{v\pi}{4}\left(\frac{6\lambda_e}{g_0 A}\right)^{1/2} \ln\left(\frac{16}{1-k^2}\right). \tag{68}$$

Evaluating the focusing distance in the Earth's gravitoelectric field, corresponding to the harmonic mode, we find

$$f \approx 5 \times 10^{-5} v(s). \tag{69}$$

Since such cylindrical superconductors (supertrons) are already built [21,25], we suggest the use of thermal neutrons (10^3 m/s) to be focused in a 5 cm cylinder, according to Eq. (69).

7. The dispersion relations: the dependence of the penetration depth on the pulsation of the electromagnetic field

Let us suppose that the current density $\boldsymbol{j}$ is determined by the contribution of the normal and superconducting electrons, i.e.,

$$\boldsymbol{j} = \boldsymbol{j}_{\mathrm{N}} + \boldsymbol{j}_{\mathrm{S}}, \tag{70}$$

where

$$\boldsymbol{j}_{\mathrm{N}} = -\sigma_{\mathrm{g}}\boldsymbol{g}_{\mathrm{g}}\boldsymbol{j}_{\mathrm{Ne}} = -\sigma_{\mathrm{e}}\boldsymbol{g}_{\mathrm{e}}, \tag{71}$$

and $\boldsymbol{j}_{\mathrm{S}}$ satisfy London equations (24) and (33). In Eq. (71), σ_{g} is the gravitational conductivity (for details see Refs. [22,23]), and σ_{e} is the electrical conductivity.

By applying the curl to Eq. (19), and taking into account Eqs. (15)–(18) and (20), (24), (26), (28) and restriction

$$\mu_{0\mathrm{g}}\sigma_{\mathrm{g}} = \mu_{0\mathrm{e}}\sigma_{\mathrm{e}}, \tag{72}$$

we obtain the propagation equation

$$\boldsymbol{B} = \left(\frac{1}{\lambda_{\mathrm{e}}^2} - \frac{1}{\lambda_{\mathrm{g}}^2}\right)\boldsymbol{B} + \mu_{0\mathrm{g}}\sigma_{\mathrm{g}}\frac{\partial \boldsymbol{B}}{\partial t}. \tag{73}$$

From here, using $\boldsymbol{B} = \boldsymbol{B}_0 \mathrm{e}^{\mathrm{i}(\boldsymbol{kr}-\omega t)}$, we find the dispersion equation

$$k^2 = \mu_{0\mathrm{g}}\sigma_{\mathrm{g}}\omega\mathrm{i} - \left(\frac{1}{\lambda_{\mathrm{e}}^2} - \frac{1}{\lambda_{\mathrm{g}}^2}\right) + \frac{\omega^2}{c^2}. \tag{74}$$

This relation embodies some interesting particular cases. They read as follows:

(i) For $B_{\mathrm{g}} = 0$, Eq. (74) reduces to the dispersion relation of the electromagnetic waves in superconductor two-fluid model [24], i.e.,

$$k^2 = \mu_{0\mathrm{e}}\sigma_{\mathrm{e}}\omega\mathrm{i} - \frac{1}{\lambda_{\mathrm{e}}^2} + \frac{\omega^2}{c^2}. \tag{75}$$

(ii) For $B_{\mathrm{e}} = 0$, Eq. (74) reduces to a dispersion relation corresponding to a gravitational perturbation, i.e.,

$$k^2 = \mu_{0\mathrm{g}}\sigma_{\mathrm{g}}\omega\mathrm{i} + \frac{1}{\lambda_{\mathrm{g}}^2} + \frac{\omega^2}{c^2}. \tag{76}$$

Taking into account Eq. (74) and Ref. [23], the refraction index has the form

$$N^2 = \frac{k^2(\omega)}{k^2(0)} = 1 - \left(\frac{\omega\lambda}{c}\right)^2 - \mu_{0\mathrm{g}}\sigma_{\mathrm{g}}\omega^2\mathrm{i}, \tag{77}$$

where

$$\lambda^2 = \lambda_{\mathrm{e}}^2\left(1 - \frac{\lambda_{\mathrm{e}}^2}{\lambda_{\mathrm{g}}^2}\right)^{-1}. \tag{78}$$

In relation (77), N^2 is complex; the real part, i.e.,

$$\mathrm{Re}N^2 = 1 - \left(\frac{\omega\lambda}{c}\right)^2 \tag{79}$$

corresponds to the transparence, and the imaginary part

$$\mathrm{Im}N^2 = -\mu_{0\mathrm{g}}\sigma_{\mathrm{g}}\omega\lambda^2 \tag{80}$$

to the absorption. Since for a superconductor $\lambda \approx \lambda_{\mathrm{e}}$, the functional dependence $\lambda_{\mathrm{e}} = \lambda_{\mathrm{e}}(\omega)$ is obtained by extending relation (26) in the form

$$\lambda_{\mathrm{e}}(\omega) = \left(\frac{\varepsilon_0|N|^2mc^2}{q^2n}\right)^{1/2} = \lambda_{\mathrm{e}}(0)|N| \tag{81}$$

with

$$\lambda_{\mathrm{e}}(0) = \left(\frac{\varepsilon_0 mc^2}{q^2n}\right)^{1/2}. \tag{82}$$

This results in

$$\lambda_{\mathrm{e}}(\omega) = \lambda_{\mathrm{e}}(0)\left[\left(1 - \left(\frac{\omega\lambda_{\mathrm{e}}(0)}{c}\right)^2\right)^2 + \left(\mu_{0\mathrm{e}}\sigma_{\mathrm{e}}\omega\lambda_{\mathrm{e}}^2(0)\right)^2\right], \tag{83}$$

which shows that the penetration depth increases with increasing pulsations of the electromagnetic field. This result is in agreement with Podkletnov's experiment [6].

8. Conclusions

The main conclusions of the present work are as follows:

1. assuming that the superposition principle is valid, we get Maxwell type equations for the generalized field (electromagnetic plus linear gravitational);
2. we get the generalized London equations;
3. we establish the conditions necessary for the generalized Meissner effect to occur;
4. the gravitational shielding in an electromagnetic field is analyzed;
5. we build the solution of differential equation corresponding to the gravitational shielding effect for an infinitely thin superconductor cylinder placed in the Earth's gravitoelectric field;
6. using this solution, we show that the oscillation modes of a neutral particle beam is cnoidal;
7. by the degeneration of cnoidal modes, we get harmonic, soliton, and solitons packet modes;
8. for the harmonic mode, we calculate the focusing length; in these conditions, we suggest an experimental test;
9. using a dispersion relation, we show that the penetration depth increases with the pulsation of the electromagnetic field.

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Does a superconductor shield gravity?

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Abstract

Recently there were some experimental observations which were interpreted as due to a shielding of the gravitational interaction by a superconducting disc in a static configuration as well as when set in rotation. We examine the experiments in detail and point out some difficulties which should be eliminated before reliable results can be claimed. The data from these experiments provide an internal check on the correctness of the hypothesis and we argue that the observed results are inconsistent with the hypothesis of shielding and therefore they are not due to shielding of the Earth's gravity. Our preliminary experiments in the static case do not show any evidence for the reported shielding.

Keywords: Superconductivity; Meissner effect; Levitation; Gravitational shielding

Recently there were experimental observations by Podkletnov et al. of an apparent reduction in weight of a sample hung above a rotating superconducting disc, for certain ranges in the rotation rate [1,2]. These results were interpreted as due to the partial shielding of the gravitational field by the rotating superconducting disc. Shielding of gravity is an important issue and so far there is no experimental evidence for such an effect, and therefore it is important to carefully study the results and data in Refs. [1] and [2]. Of course, there is no theoretical framework at present which can give rise to such a shielding and any such effect can only be due to some effect which is beyond the general theory of relativity, possibly from quantum effects and so on. The problem even with such a view is that the measured effect is very large, amounting to more than 1% shielding of the local gravitational field. If the coupling which gives rise to such a shielding depends on fundamental constants like G, c, and h, then such a large shielding is certainly very unnatural for situations involving small gravitational fields and small velocities. In fact, since one is looking at the Newtonian field (the electric part of the full gravitational interaction, with the Newtonian potential ϕ given by $1 + 2\phi = g_{00}$, where g_{00} is the time–time component of the metric), the expectation would be an enhancement of the weight since the superconductor is in rotation and the rotational energy should contribute to the effective mass and effective gravity. But this effect also is very small, being of the order of $GI\omega^2 m/c^2 r$, where I is the moment of inertia of the disc and r the typical separation between the disc and test mass m. Such effects amount to corrections to the weight of less than 10^{-23}!

A fundamental difference between electromagnetism and gravitation is the fact that in gravity there is only one type of charge as far as we know and therefore many phenomena in electromagnetism which involve two types of charges are absent in gravitation. That is why there is no shielding of the Newtonian

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gravitational field. With Einstein's theory the situation regarding shielding is not different; in fact, in general relativity typically the potential is enhanced due to other interactions since they also contribute to gravity with the same attractive sign. But there is the possibility that some part of the potential is diminished in the presence of an object like a superconductor where there are macroscopic quantum effects. An analogue of the Meissner effect could be thought of in which the gravitomagnetic potential (from the g_{0i} part of the metric) is shielded by the superconducting electrons. There is a difficulty, however, since the corresponding penetration depths are very large and therefore it is equivalent to no shielding at all in any imaginable situation. In any case such a shielding or enhancement, if any, cannot affect the weight of a test mass since the gravitomagnetic effects are velocity dependent and do not exert a force on any static object.

The reasons for starting with a pessimistic view on the results presented in Refs. [1] and [2] are threefold:
(1) the theoretical framework of the phenomenon of classical gravity is now well tested and general relativity has emerged as more or less the correct theory describing all known gravitational phenomena.
(2) In a recent experiment measuring the levitation force on magnets near a superconductor in static situations we have not seen any anomalous weight reduction even though our sensitivity was about 50 times higher than what was required to see the effect seen by Podkletnov in the static situation, and
(3) new results obtained by Podkletnov [2] in an improved experimental situation are internally inconsistent as we will argue in this paper. All these point to the need for better experiments with several control experiments to compare with.

Before we discuss these results, it is appropriate to highlight the essential details of the experiment, as described in Refs. [1] and [2]. A large superconducting toroidal disc (YBCO, cooled in He vapour around 60 K) was levitated by the Meissner effect in an oscillating magnetic field and then rotated with rotating magnetic fields. The weight of a SiO_2 sample (and several other samples in the later experiments) hung from a balance was measured as a function of the rotation rate. They report fluctuating weight readings, including both increase and decrease for some ranges of rotation rates and there are reproducible values of the reduction in weight for a certain range of rotation rate. Also, there is some weight reduction noticed when the disc is not rotating at all. The reduction is around 0.05% for the static situation and it is 0.1% when the disc is rotating. The fluctuating values are also very large, a few percent.

In a more recent version of the experiment [2], the rotating superconducting disc was housed in a cryostat to avoid air currents during rotation. In all these experiments the weight reduction of the sample amounting to even 2% was seen. Also, it was observed that the shielding and weight reduction was independent of the distance above the rotating disc. We will argue later that this fact is inconsistent with any natural model of shielding of the Earth's gravity.

Before we discuss the internal inconsistency of Podkletnov's data, we would like to make some comments about the possibilities suggested by Podkletnov for the shielding of gravity. Any mechanism which invokes additional magnetic lines inside the superconductor affecting the gravitational interaction itself will not work since the energy stored in flux lines will be proportional to B^2, and it is positive. This can only enhance the gravitational effect, though such enhancements are minuscule. Classically, the gravitational constant itself cannot be modified by the stored magnetic field, whichever way it is distributed between the grain boundaries of the superconductor. So, even if the effect is genuine it has to come from a new interaction and there are some attempts to invoke such a mechanism [3]. A more probable cause would be unidentified electromagnetic interaction (this could be from pinned flux lines rotating with the disc, for example) or more mundanely, but more probably, air currents and drags due to temperature gradients and rotation affecting the sample on the balance. There is good reason to believe that this might be a factor in at least some of the experiments reported in Refs. [1] and [2], since it was seen that the shielding is better when the sample is kept such that its projected area above the rotating disc is maximum, very characteristic of levitation by air currents.

Now we will elaborate on an important internal consistency check available in Podkletnov's data, which rules out shielding of Earth's gravity by the rotating superconducting disk. Podkletnov has done experiments in which the rotating disc was enclosed in a cryostat to eliminate air currents affecting the measurements.

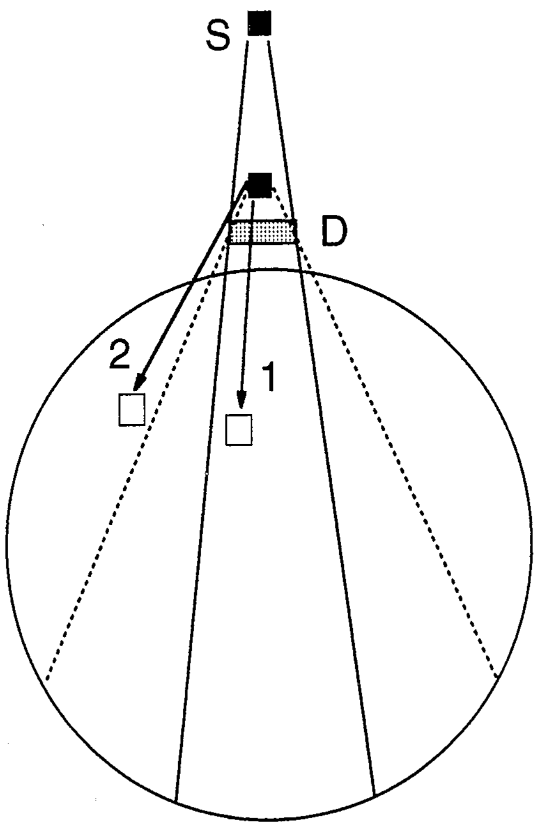

Fig. 1. Diagram showing the decrease of volume and mass of the Earth which can be shielded in principle by the disc (D), as a function of the distance of the sample (S) above the disc. See text for details.

But, this does not eliminate convection currents outside the cryostat and in fact the experimenters state that an annular cylindrical flow of air is clearly visible above the cryostat (the disc used also is annular). Fortunately, Podkletnov has measured the weight of the sample above the disc for various distances from the disc and one of these measurements is done in a room above the room in which the disc was rotating. As mentioned earlier the shielding was found to be independent of the distance of the sample above the rotating disc. The observation of weight reduction when the sample is kept in a separate room above the room where the disc was rotating helps in quenching doubts about the role of air currents in the observed weight reduction. But the observed distance independence contradicts the shielding hypothesis and it provides the crucial test of the hypothesis of shielding of the earth's gravity. It is known from Newton's time that the Earth's gravity (or gravity of any spherical body) when added as a vectorial interaction acts as if the whole mass is concentrated at the centre. This of course does not mean that the source is concentrated at the centre (even if the centre is hollow, this result remains true). For any arbitrary mass distribution the correct total gravitational field is given by the vectorial integral of the field from elementary masses distributed throughout the large mass. Therefore, in any hypothesis of shielding what is important is the mass of the Earth as seen by the sample being weighed. If the vector connecting the sample and a mass element passes through the disc (like the arrow numbered "1" in Fig. 1), there is a possibility of shielding of gravity of that particular mass element, but if the disc does not intersect the vector (arrow numbered "2") then the sample will be pulled by gravity of that mass element. Referring to Fig. 1, it is clear that only the gravitational force from the region inside the intersection of the cone with the spherical earth would be shielded in the configuration shown and that the rest of the Earth's gravity will still pull down on the sample. The figure also shows the fact that the shielded region diminishes in volume as the distance (h) between the sample and the disc is increased. The region which could be shielded has the approximate shape of a truncated cone and it is easy to estimate that the reduction is shielding as the height of the sample above the disc is increased. Since the radius of the earth (R) is very large compared to the diameter (d) of the disc and the height h, the mass which is effectively shielded can be approximated as that of the cone and is given by $M_c = (2\pi\rho_c/3)\,(d^2R^3)/h^2$, where ρ_c is the average density of the conical region. The mass of the earth is given by $M = (4\pi\rho R^3)/3$. The ratio of the masses is $M_c/M = \rho_c d^2/(2\rho h^2)$. To find the ratio of the gravitational contributions from the whole earth and the conical region, we need to include the angular factors and integrate the contributions from elementary masses in these regions with the density as a function of radius. For $d \simeq 20$ cm, and $h \geq 100$ cm, the volume of the conical region ($d^2/2h^2$) is less than 1% of the volume of the earth and then the angle factors are not important for an approximate estimate. (Podkletnov has taken data up to a distance of 300 cm, and the disc is actually toroidal with an outer diameter of 24.5 cm and an inner diameter of 8 cm. We approximate the effective shielding diameter to around 20 cm and estimate the effects for a circular disc.)

Even after allowing for the fact that ρ_c is somewhat larger than (but less than a factor of 2) ρ, we can see that the shielding should reduce significantly for distances much larger than the diameter of the disc, since the reduction is quadratic in d/h. For $d/h \simeq 5$, the shielding should be only about 5% of its value at $d/h \simeq 1$, and for $d/h \simeq 10$, this should have reduced to about 1%. For the largest value of $d/h \simeq 15$ in the experiment, the shielding would diminish to 0.05% of its value near the disc and this distance dependence is not observed in Podkletnov's experiments. On the contrary the shielding was seen to be accurately distance independent. The observed shielding is around 1%–2% near the disc as well as 3 m above the disc whereas it should have diminished to less than 0.01% at these heights. Similar results have been obtained by Modanese employing a Monte Carlo simulation [4]. This crucial consistency check clearly points to some spurious reason for the data observed by Podkletnov and rules out shielding of the earth's gravity as a possible explanation.

In addition to this consistency check, which is the most significant point, we want to point out some additional facts which supports the suspicion that the observed effect is not due to shielding of gravity. We conducted two simple experiments to check for shielding in the following cases:

(1) Measurement of the weight of a sample hung above a superconducting YBCO disc in the superconducting state, immersed in liquid nitrogen, without rotation or magnetic field.

(2) Measurement of the weight of the sample over the disc when there are static magnetic fields below the disc, generating supercurrents, but with the disc nonrotating.

The sensitivity of these measurements (using a Metler AE240 balance) was such that a weight change of 0.001% could be measurable. In the first measurement we did see a weight reduction amounting to 0.05% or so, but the same weight reduction was observed even when the superconducting disc was removed, but the liquid nitrogen dewar remained in place! The observed weight reduction in this case was verified to be due to the additional buoyancy in the cold nitrogen atmosphere and partly due to air currents from evaporating nitrogen.

In the second measurement with magnets directly underneath the superconducting disc, the results were the same as in the first set and this suggests that the weight reduction observed by Podkletnov in the static situation is spurious (the magnetic field was about 20 times the lower critical field and considerable flux penetration was expected). Of course, we have not reproduced exactly the same experimental condition as in Podkletnov's experiment, but we certainly have reproduced some of the physical ingredients which could have given such an effect, like supercurrents. Also, Podkletnov's experiments were done at a lower temperature. It might still be worthwhile to do an experiment replicating Podkletnov's experiment, but the real value of such an experiment would be in finding out whether it is buoyancy-related effects or electromagnetic effects that are responsible for the observed data.

It is possible to improve the experiments described in Refs. [1] and [2] on several fronts. The overall sensitivity itself can be improved by a factor of 5 to 10 using better commercial balances and this will allow a more careful measurement to be made on the weight changes as a function of height from the disc as well as with position in the horizontal plane over the disc. To see whether free rotation without time-varying electromagnetic fields can lead to weight changes, the disc can be rotated with a gas jet and the levitation itself can possibly be done on static magnetic fields. It is also important to get the functional dependence of the weight change on the rate of rotation. A more convincing data set could be obtained by keeping the sample on the balance in a chamber isolated from the disc, to avoid air currents, and repeatedly rotating and stopping the disc to see whether there are any reproducible periodic weight changes.

In summary, we have analysed the data from Podkletnov's experiments on the shielding of gravitational field by a superconductor and concluded that the data fail to pass a crucial consistency test. This is important since it is not easy to repeat Podkletnov's experiments exactly and the claimed effect touches fundamentally important issues. Our critique of the claim is more or less independent of the model assumed for possible shielding and thus the shielding of gravity by rotating or static superconductors at the level of 0.05% is ruled out. We have also conducted some preliminary experiments in the static situation and there is no evidence for any shielding.

Acknowledgements

I thank V.P.S. Awana for drawing my attention to a paper by G. Modanese and for lending YBCO discs. I am thankful to G. Modanese and E. Podkletnov for several clarifications.

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GENERATION OF ANTI-GRAVITY OWING TO COUNTERCLOCKWISE TURNING OF GYROSCOPE

Hayasaka, Hideo

Abstract

The weight reduction owing to the counterclockwise turning of a gyroscope discovered by Kozyrev, is considered as the perturbation to the clockwise turning. The perturbation is due to the singularity of time concerning a mirror transformation. The singularity of time corresponds to the singularity of space expressing a mass point in gravitational field and leads to the generation of **anti-gravity.** The condition of no weight change in the clockwise turning leads to the reduction of the gravitational acceleration in the counterclockwise turning; that is, the counterclockwise turning of a gyroscope creates positive potential energy and then generates the **anti-gravity.** [17 Refs]

Index Terms: GRAVITATION

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RELATIVISTIC MECHANISM OF LOCAL VANISHING OF THE ATTRACTIVE FIELD OF THE EARTH BY VIRTUE OF THE LEFT TURNING MOTION OF A MATTER

Hayasaka, Hideo

Abstract

The phenomenon of weight reduction in the left turning of a gyroscope discovered by Kozyrev, is explained from the spontaneous symmetry breaking of Christoffel's affinity for left and right turnings. The spontaneous symmetry breakdown is due to the appearance of the latent singularity in the action integral concerning the moment of gravity generated by turning motion with the flow of time. The left turning of gyroscope adds positive potential energy to the gyroscope by absorbing energy from the flow of time and then generates **anti-gravity.** [50 Refs]

Index Terms: GRAVITATIONAL EFFECTS; GYROSCOPES

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Gravity's quantum leaps detected

19:00 16 January 02

Gravity's subtle influence in the quantum world has been directly observed for the first time.

On tiny scales, nature makes particles behave according to curiously rigid rules. For instance, negatively charged electrons trapped around a positive nucleus under the pull of the electromagnetic force cannot have any energy they want -they have to fall into a set of distinct energy levels.

In the same way, the pull of gravity should make particles fall into discrete energy levels. But because gravity is extremely weak on small scales, the effect has been impossible to spot. "To be able to measure it, you need to suppress interference from all the other fields," says Valery Nesvizhevsky of the Laue-Langevin Institute in Grenoble, France.

Now Nesvizhevsky and his colleagues have achieved the feat using a beam of neutrons. Neutrons were ideal because they're neutral, so they don't feel the electromagnetic force and can ignore its quantum rules.

"The experiment is a real tour-de-force in making the first demonstration of a quantum effect due to gravity," says Thomas Bowles of Los Alamos National Laboratory in New Mexico. "Although everyone feels the pull of gravity on their bodies, the pull of gravity on a neutron is smaller by more than a trillion trillion times."

Bowles says the accuracy of the experiment is stunning. "Imagine putting a 747 aeroplane on a scale and weighing it. Then take one grain of sand and add it to the scale. The fractional change you would observe on the scale readings would still be a billion times larger than the fractional change that Nesvizhevsky was able to observe in their experiment."

Bouncing neutrons

Nesvizhevsky's team took a beam of ultracold neutrons with tiny energies, moving from left to right at less than eight metres per second. Under the force of gravity, the neutrons fell down onto a reflecting mirror and bounced off it before arriving at a detector.

The team could limit the energies of the neutrons arriving at the

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detector by placing an absorbing material at different heights above the mirror. The material mopped up all the neutrons that bounced too high.

Forgetting quantum mechanics, you would expect neutrons with any energy to arrive at the detector. But no neutrons appeared unless the neutron-mop was at least 15 micrometres above the mirror. This means the neutrons have to have a certain, minimum energy (equal to 1.41×10^{-12} electronvolts) in the Earth's gravitational field.

Step up

There were also hints that neutron transmission took little leaps at different, higher energies, corresponding to higher quantum levels. However, the team has still to confirm this.

Nesvizhevsky says the technology is exciting because it could test some other key ideas in physics - for instance, whether or not the neutron carries some minuscule amount of electric charge. "If it's there, it's very, very small," says Nesvizhevsky.

It could also put on trial the equivalence principle, a famous concept of Einstein's. It says that all particles, regardless of their mass or composition, should fall with the same acceleration in a uniform gravitational field.

Journal reference: *Nature* (vol 415, p 297)

Hazel Muir

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Anti-gravity research on the rise

12:31 30 July 02

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Researchers around the world are opening their minds to the possibility that the phenomenon of anti-gravity is not just science fiction.

Most respected physicists still scoff at the idea that experimental equipment can reduce gravity, but several groups have been working on it independently and are coming to the same conclusion: it might just be true.

On Monday, reports re-emerged that Boeing, the American aircraft manufacturer, is interested in exploring the possibility of building an anti-gravity device. The news, first revealed in **New Scientist** magazine in January 2002, centres around Russian scientist, Evgeny Podkletnov. In 1992 he claimed to be the first person to witness the reduction of gravity above a spinning superconducting disc.

Podkletnov, a specialist in superconductors, says he stumbled on the effect whilst performing a routine test on a large superconductor in his laboratory at the Tampere University of Technology, Finland.

High speed spin

Podkletnov met **New Scientist** in late 2001 to outline the experiment, in which a large yttrium-barium-copper-oxide (YBCo) superconducting disc was suspended in nitrogen vapour and cooled to around —233 °C. The disk was levitated in a magnetic field and finally spun at speeds of up to 5000 revolutions per minute by means of an alternating electric current.

He claimed that objects placed above the disc lost around one per cent of their weight. But so far no one has managed to successfully repeat his experiment.

However, several high-profile organisations have taken an active interest in his work. NASA has paid Superconductive Components of Columbus, Ohio, $600,000 to reproduce the apparatus Podkeltnov used in his experiment. There have been delays, but NASA's Ron Koczor told **New Scientist**: "We expect to be ready to test the device in late September 2002."

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British defence contractor, BAe Systems, is also interested in the work and set up Project Greenglow to explore the subject. Other groups in Japan, France and Canada are also rumoured to be working on the subject though they have so far kept their identities secret.

Predicted effect

The most intriguing aspect of the affair is that Ning Li, then at the University of Alabama, Huntsville, says she independently predicted Podkletnov's observation in 1989.

Li's theory predicts that if a time-varying magnetic field were applied to a superconductor, charged and deformed lattice ions within the superconductor could absorb enormous amounts of energy. This would cause the lattice ions to spin rapidly about their equilibrium positions and create a minuscule gravitational field.

Li claimed that if these charged, rotating, lattice ions were aligned with each other by a strong magnetic field, the resulting change in local gravity would be measurable.

Early in 2002, Raymond Chiao, a respected physicist at the University of California at Berkley, put forward his own theory relating gravity and superconductors. He predicted that bombarding a superconductor with electromagnetic waves would produce gravitational radiation and is now attempting to prove his theory by experimentation.

David Cohen

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Date: Fri, 11 Jan 2002

Evgeny Podkletnov has convinced NASA to spend $600,000 on a machine he claims will shield matter from the Earth's pull. Has the agency flipped? David Cohen tracked down the man who wants to turn the laws of physics on their head

Going up

SEATED in a near-empty restaurant in a backstreet of Tampere in Finland, Evgeny Podkletnov certainly doesn't look crazy-even when he holds up the superconducting disc he says he used to reduce the effects of gravity. The Russian emigre's claim caused such a storm he was thrown out of his job at Tampere University of Technology five years ago. He now works as a researcher in superconducting materials at the nearby University of Tampere, but he's not about to give up his quest to be taken seriously.

Podkletnov claims others have repeated the experiments with great success, and for the moment at least, influential scientists around the world are giving him the benefit of the doubt. Researchers at Toronto University in Canada, at CNR5--France's national research agency-and even an employee of Boeing in the US all want to repeat his experiment, Podkletnov says. And perhaps most significantly of all, NASA is ready to give the idea a shot. This month, after a two-year wait, Ron Koczor and his team at NASA's Marshall Space Flight Center in Huntsville, Alabama, will take delivery of a machine that Koczor believes could shield matter from gravity.

Koczor persuaded NASA to pay Superconductive Components (SCI) of Columbus, Ohio, $600,000 to build a copy of Podkletnov's apparatus. If SCI,s replica works, it could change our way of interacting with a fundamental force of nature. And that, Koczor says, would change everything. Wave goodbye to rockets and the internal combustion engine. Say hello to energy-saving gravity-powered spaceships, aeroplanes, cars and elevators-and a whole new branch of theoretical physics.

Koczor is aware of what the critics will say, but he believes there are hints that it might work and he is determined to keep an open mind. This kind of investigation lies within the Marshall Center's remit to seek out new and exotic forms of propulsion and the potential payoff is huge, he says. "It's worth a little bit of effort to pursue it to its end." But that "little bit of effort" is, essentially, a gamble on Podkletnov's claims. In 1992 he published a paper describing how he had stumbled across a "gravity shielding" effect while running a routine test on one of his superconductors. The details were sketchy. But the basics are these: make a superconducting disc 145 millimetres in diameter and 6 millimetres thick, according to a special chemical recipe that Podkletnov did not make public. Cool the disc to below -233C, then levitate it using a magnetic field. Finally, apply an electric current alternating at around 100 kilohertz to coils surrounding the disc. The current makes the disc rotate in the constantly changing magnetic field, something like an electric motor (see Graphic). So far, there's nothing extraordinary here.

But Podkletnov claimed that when the disc was spinning at more than 5000 revolutions per minute, objects placed above it lost around 1 per cent of their weight. Increasing the spin speed, he claimed, reduced their weight still further. In subsequent experiments, he claims to have seen weight reductions of up to 2 percent.

Podkletnov concluded that this apparatus somehow reduced the strength of the Earth's pull on any object placed above it and called it a "gravity shielding" device. Stick a more powerful version of this apparatus on the bottom of a spacecraft and rocket propulsion would be history: just the slightest nudge would be needed for lift-off into space. Terrestrial transport would be revolutionized too, together with a large chunk of theoretical physics.

At the time, the paper was greeted without fanfare. It would probably have been forgotten, but for the fact that Podkletnov continued his experiments and, in 1996, produced another paper. Physica D reviewed and accepted it, but its contents were leaked to the press before publication. "The world's first anti-gravity device", as The Sunday Telegraph in Britain called it, was rubbished by scientists around the globe, who loudly proclaimed that it broke the known laws of physics. In the academic scuffle that ensued, Podkletnov was dismissed from his post. After withdrawing the paper (to protect his co-author's career, he says) he disappeared-for a while, at least. I caught up with him in Tampere at the end of last year and found him still adamant that his superconducting disc can shield matter from gravity.

Podkletnov has the air of a persecuted man. While talking about his work his mood shifts constantly between suspicion, seriousness and wild excitement-there are echoes of the cold fusion debate here. But his frustration is clear. "I am a professional scientist and have published more than 30 papers and hold many patents, " he says. "Some people say 'Podkletnov is a fool,' but there are too many other people in the world who have seen this and they all can't be wrong." His English is almost perfect with only a faint Russian accent. He peppers his conversation with references to private conversations with eminent scientists who would come right out and support him, were they not so scared of losing their credibility.

His confidence-and Koczor's-stems from the fact that he is not alone in suggesting a way to modify gravity. In 1995, Koczor and his team were approached by Ning Li, a researcher at the University of Alabama in Huntsville. Li had never met or even heard of Podkletnov, yet she was developing a theory, based on the idea of converting electromagnetic fields into gravitational fields, that came very close to explaining Podkletnov's experiment. She claimed her theory pointed to the possibility of producing a "gravito-magnetic effect" by spinning it super cooled superconducting disc: the angular momentum of fast-spinning ions in the superconductor would produce a gravitational field, she said. By 1995 Li felt she had reached the point where she could approach NASA to fund an experimental test of her ideas.

"We were interested in her theories," says Koczor. "But we thought her experiment was undoable." Then, ina literature search, Koczor and Li found Podkletnov's 1992 paper in the journal Physica C. "We were intrigued. It was essentially the same experiment, only simpler," Koczor says. "Physica C is not a trivial journal. If (the experiment] got in there then it must have got through sufficient scientific vetting to take to a higher level, so we decided we'd try it ourselves."

For the following two years, Koczor and Li tried to duplicate Podkletnov's experiment. They bought some small superconducting discs, levitated them, put high-frequency electromagnetic fields into them and did a few experiments to measure the gravitational effects. "We tried to see if there was one or other of these factors that could be isolated and identified as responsible for the Podkletnov effect," explains Koczor.

Their experiments were unsuccessful. In 1997 Koczor's team reported their lack of findings in Physica C, saying that for their 10-centimetre discs the measurable effect on gravitational pull was a mere two millionths of 1 per cent-small enough to have been background noise in the measuring equipment. But they were not disheartened.

"Podkletnov told us we wouldn't see any effect unless we repeated his experiment faithfully," Koczor says. "We never did the full Podkletnov experiment-we were still learning to work with these superconductors." And so the team focused on producing a 30-centimetre yttrium-barium-copper-oxide (YBCO) superconducting disc like that used by Podkletnov. But they still didn't have his recipe. Eventually, in 1999 Koczor gave up and commissioned SCI to build a replica of Podkletnov's apparatus. At the same time, Li set up an independent laboratory to pursue the research. SCI contracted Podkletnov as a consultant on its project, asking him to advise on some technical aspects of building the superconductor. "Podkletnov has been as helpful as he could be to get our mission fulfilled," says J.R. Gaines, vice president and general manager of SCI. And so this month-a year behind schedule-Gaines will hand over the finished apparatus.

High hopes

NASA is not the only bona fide organization that has been taking Podkletnov seriously. When British military and aerospace company BAE Systems learned that Clive Woods, a superconductor researcher from Sheffield University, was trying to replicate the experiment it decided it too would hedge its bets and help fund his attempts. "We know we're out on a limb," says Ron Evans, director of Project Greenglow-BAE Systems' research program into alternative forms of propulsion. "But even though we got negative advice from several professors, it seemed to me that for a small amount of money it's worth the gamble. Experts have been wrong before and that's the only thing that makes it worth doing."

Evans is giving Woods an undisclosed sum to reproduce Podkletnov's experiment. So far Woods, too, has been unsuccessful. Like Koczor, Woods believes this could be because he has not managed to reproduce all the conditions Podkletnov says are necessary-the specifications are extremely demanding. &That does not mean there is no effect to be observed, Woods says.

Meanwhile, Podkletnov has been quietly continuing his research. "I am not a rich man," he says. "But I have some funds from other projects and I put everything I have into gravity research. This is my life's dream, my hobby, my goal."

He has made good progress, he says. With the help of friends in a laboratory that once belonged to Moscow's Institute for High Temperatures, he claims to have built an "impulse gravity generator". He says its pulse-produced by a spinning superconductor with a strong electrical charge-is capable of knocking over a book placed on end more than a kilometre away.

The pulse has the same properties as a gravitational field, says Podkletnov. It is unaffected by an inch-thick steel plate fixed in the beam path, and the force it exerts is changed only with the target's mass, not its constituent material nor its chemical or electromagnetic properties. As he talks about it, he suddenly becomes animated. He thinks it could one day be used to nudge satellites into the correct orbit, and even knock incoming missiles off course. "This is a very powerful device, and I am now in the process of arranging a future project on the gravity generator with serious European firms," he says, almost in a whisper. But, he adds, he cannot divulge which firms-he has signed confidentiality agreements. Although Podkletnov is happy to discuss is work, he says no one can come and look at the gravity pulse experiment. It requires extremely high voltages, and the required generating equipment is, unfortunately, in a restricted area of Moscow State University's campus. So he refused my request to watch the gravity generator in action.

Evans, too, has suggested that an independent observer might visit Podkletnov's Moscow laboratory. Again, Podkletnov refused. "He told me that he once hosted some Japanese visitors to his lab, but they tried to bribe his technicians for the secrets on how the experiment worked," Evans says. &As a result he decided not to bring any other visitors."

Podkletnov, who says he is in the process of patenting his work, is also scared someone might steal his intellectual property rights to the experiment. But Robin Tucker, a theoretical physicist at Lancaster University who is also investigating possible ways to control matter with gravity, thinks Podkletnov's secretive behaviour is odd, to say the least. &Any normal physicist who found this kind of effect would be shouting about it from the tops of the trees and asking people to come and verify it," he says. "It would mean a Nobel Prize if you'd actually discovered some kind of gravity focusing."

Podkletnov's refusal to open up to scrutiny leaves the scientific world lacking any independent, verifiable observations of gravity modification. He gave me an untraceable e-mail address for a Takashi Nakamura, who he claimed was a senior physics professor employed at Toshiba Electronics in Japan. Nakamura responded to my e-mail question, saying that he had managed to reproduce Podkletnov's experiments with even better results. "With all my respect to Evgeny-san, our ceramics is better and we got 8.79% of the weight reduction," he wrote. "Our programme of research has already shown much better efficiency."

However, when I asked for references documenting these results, Nakamura terminated the correspondence.

Quantum suspects

Podkletnov's only current collaboration is with Giovanni Modanese, an Italian physicist who is trying to build a theoretical explanation for Podkletnov's results. But because physicists have such a poor understanding of the mechanisms behind both gravity and high-temperature superconductivity, his explanations are necessarily vague. He suggests that quantum processes within the superconducting material are interacting with quantum processes in the gravitational field. But, he admits, he can't go far with the work because there, are too many unknowns. Again, Tucker is skeptical even of this attempt to formalize what's going on. "I think the correlation between the experiment and the theoretical description is very tenuous, " he says.

So, frustrating as it is, that's as much as we know at the moment. I contacted several of Ning Li's ex-colleagues, but all said they did not know of her current whereabouts or the state of her research. NASA and BAE Systems still don't know whether they have been sent up a blind alley by Podkletnov's enthusiasm. But Koczor believes he'll soon have the answer. "Running the experiment will take six months at most," he says. If it fails to confirm Podkletnov's experiment, that will be the end of the matter. But if the experiment succeeds, and they can modify gravity, then who knows what could be possible? In the end, pigs really might fly.

Update From Eugene Podkletnov <epodkletnov@hotmail.com> July 02, 2002
It might be possible that the wobble in the superconductor experiments is favorable for the antigravitational effect but I don't think that it is the main reason for the effect. In my experiments the key element is creating a super high density of electrons or Cooper pairs that move in strong magnetic field. Actually, antigravitation is caused by the polarization of vacuum or polarization of sub-atomic particles that constitute the vacuum. There exist several methods of causing this polarization:
1. High speed rotation (80 thousand rpm) of metal crystal lattice. 2. Rotation of magnetic fields that coincide in phase with electric field. 3. High voltage static electric field (the lifter). 4. Resonance frequencies using ELF waves and De Aquino configuration. 5. Topological effect, using grids with special geometry 6. Acoustical vibration at resonance frequencies.
Comment from editor: Podkletnov mentions "antigravitation is caused by the polarization of vacuum." Is gravity a vacuum polarization effect? Perhaps yes? See Polarizable-Vacuum (PV) representation of general relativity by H.E. Puthoff
New Scientist Update 30 July 02,

Anti-gravity research on the rise. Researchers around the world are opening their minds to the possibility that the phenomenon of anti-gravity is not just science fiction. And related to this please see Reverse Engineering at Area- 51? Were Einstein and others involved in the initial program?

Additional References

Static Test for a Gravitational Force Coupled to

TYPE II YBCO Superconductors,

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Possible quantum gravity effects in a charged Bose condensate under variable e.m. field,

Impulse Gravity Generator Based on Charged YBa_2Cu_3O_{7-y} Superconductor with Composite Crystal Structure and,

Role of a "Local" Cosmological Constant in Euclidean Quantum Gravity Also, related to this please see Stiff challenge to space-time, Einstein's theory of relativity tells us that gravity bends space. Now a physicist at the University of Portsmouth, UK, has worked out that magnetic fields may smooth bent space.

Polarizable-Vacuum (PV) representation of general relativity

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ABSTRACT

Standard pedagogy treats topics in general relativity (GR) in terms of tensor formulations in curved space-time. Although mathematically straightforward, the curved space-time approach can seem abstruse to beginning students due to the degree of mathematical sophistication required. As a heuristic tool to provide insight into what is meant by a curved metric, we present a polarizable-vacuum (PV) representation of GR derived from a model by Dicke and related to the *"TH$\varepsilon\mu$"* formalism used in comparative studies of gravitational theories.

I. INTRODUCTION

Textbook presentations treat General Relativity (GR) in terms of tensor formulations in curved space-time. Such an approach captures in a concise and elegant way the interaction between masses, and their consequent motion. "Matter tells space how to curve, and space tells matter how to move [1]."

Although conceptually straightforward, the curved space-time approach can seem rather abstract to beginning students, and often lacking in intuitive appeal. During the course of development of GR over the years, however, alternative approaches have emerged that provide convenient methodologies for investigating metric changes in less abstract formalisms, and which yield heuristic insight into what is meant by a curved metric.

One approach that has a long history in GR studies, and that does have intuitive appeal, is what can be called the polarizable-vacuum (PV) representation of GR. Introduced by Wilson [2] and developed further by Dicke [3], the PV approach treats metric changes in terms of equivalent changes in the permittivity and permeability constants of the vacuum, ε_o and μ_o, essentially along the lines of the so-called *"TH$\varepsilon\mu$"* methodology used in comparative studies of gravitational theories [4-6].

In brief, Maxwell's equations in curved space are treated in the isomorphism of a polarizable medium of variable refractive index in flat space [7]; the bending of a light ray near a massive body is modeled as due to an induced spatial variation in the refractive index of the vacuum near the body; the GR reduction in the velocity of light in a gravitational potential as compared to a flat-space reference frame at infinity is represented by an effective increase in the refractive index of the vacuum, and so forth. As elaborated in Refs. [3-7], PV modeling can be carried out in a self-consistent way so as to reproduce to appropriate order both the equations of GR, and the match to the classical experimental tests of those equations. In what follows we shall continually cross-reference PV-derived results to those obtained by conventional GR techniques to confirm that the PV approach as applied does not introduce spurious results.

II. THE POLARIZABLE VACUUM

At this point one approach would be to introduce an appropriate Lagrangian for the PV formulation, and then derive equations of motion. Recognizing, however, that the PV approach is likely unfamiliar to most readers, we defer such formal derivation to Section IV. In its place we simply present and apply here certain key results of the more formal derivation to problems of interest, such as the three classical tests of GR. In this way we build up for the reader an intuitive picture of what is meant by a polarizable-vacuum representation of curved space-time.

Under non-curved-space conditions the electric flux vector $\boldsymbol{D}$ in a linear, homogeneous medium can be written

$$\boldsymbol{D} = \varepsilon \boldsymbol{E} = \varepsilon_o \boldsymbol{E} + \boldsymbol{P} \tag{1}$$

where ε and ε_o are the permittivities of the medium and of the vacuum, respectively, and the polarization $\boldsymbol{P}$ corresponds to the induced dipole moment per unit volume in the medium. Writing $\boldsymbol{P}$ in terms of the polarizability per unit volume, α_V, as $\boldsymbol{P} = \alpha_V \boldsymbol{E}$, we obtain the symmetrical form

$$\boldsymbol{D} = \varepsilon_o \boldsymbol{E} + \alpha_V \boldsymbol{E} \, . \tag{2}$$

The above expression leads naturally to the interpretation of ε_o as the polarizability per unit volume of the vacuum, treated as a medium in its own right. That this interpretation is correct is explicitly corroborated in detail by the picture of the vacuum as developed in quantum field theory. There it is shown that the vacuum acts as a polarizable medium by virtue of induced dipole moments resulting from the excitation of virtual electron-positron pairs [8].

With regard to representing curved-space conditions, the basic postulate for the PV approach is that the polarizability of the vacuum in the vicinity of, say, a mass differs from its asymptotic far-field value by virtue of vacuum polarization effects induced by the presence of the body. That is, we postulate for the vacuum itself

$$\boldsymbol{D} = \varepsilon \boldsymbol{E} = K \, \varepsilon_o \boldsymbol{E} \, , \tag{3}$$

where K is the (altered) dielectric constant of the vacuum (typically a function of position) due to (GR-induced) vacuum polarizability changes under consideration. *Throughout the rest of our study the vacuum dielectric constant K constitutes the key variable of interest.*

We next examine quantitatively the effects of a polarizable vacuum on the various measurement processes that form the basis of the PV approach to general relativity.

A. Velocity of Light in a Vacuum of Variable Polarizability

We begin our discussion of the polarizable-vacuum model by examining constraints imposed by observation. An appropriate starting point is the expression for the fine structure constant,

$$\alpha = \frac{e^2}{4\pi\,\varepsilon_O \hbar c} \ , \quad \text{where} \quad c = \frac{1}{\sqrt{\mu_O \varepsilon_O}} \ . \tag{4}$$

By the conservation of charge for elementary particles, e can be taken as a constant. Similarly, by conservation of angular momentum for a circularly polarized photon propagating through the vacuum (even with variable polarizability), $\hbar$ can be taken as a constant. Given that ε_O and c can be expected with a variable vacuum polarizability to change to $\varepsilon(K) = K\varepsilon_O$ and $c'(K) = 1\big/\sqrt{\mu(K)\varepsilon(K)}$, the fine structure constant takes the form

$$\alpha = \frac{e^2}{4\pi\,\varepsilon_O \hbar c}\sqrt{\frac{\mu(K)/\mu_O}{K}} \tag{5}$$

which is potentially a function of K.

Studies that consider the possibility of the variability of fundamental constants under varying cosmological conditions, however, require that the fine structure constant remain constant in order to satisfy the constraints of observational data [9-11]. Under this constraint we obtain from Eq. (5) $\mu(K) = K\mu_O$; thus the permittivity and permeability constants of the vacuum must change together with vacuum polarizability as

$$\varepsilon_O \rightarrow \varepsilon = K\varepsilon_O \,, \qquad \mu_O \rightarrow \mu = K\mu_O \ . \tag{6}$$

This transformation, which maintains constant the ratio $\sqrt{\mu/\varepsilon} = \sqrt{\mu_O/\varepsilon_O}$ (the impedance of free space) is just what is required to maintain electric-to-magnetic energy ratios constant during adiabatic movement of atoms from one point to another of differing vacuum polarizability [3]. Detailed analysis shows that it is also a necessary condition in the $TH\varepsilon\mu$ formalism for an electromagnetic test body to fall in a gravitational field with a composition-independent acceleration (WEP, or weak equivalence principle, verified by Eötvös-type experiments) [4-6]. Finally, this condition must be satisfied by any metric theory of gravity, which constitutes the class of viable gravity theories.

The above arguments therefore lead us to our first major conclusion concerning the effects of a variable vacuum polarizability; namely, the permittivity and permeability constants, ε and μ, change linearly with the vacuum dielectric constant K as given in Eq. (6), and the velocity of light therefore changes inversely with K in accordance with

$$c\,(=1\big/\sqrt{\mu_O\varepsilon_O}\,) \longrightarrow c/K \ \ (=1/\sqrt{\mu\varepsilon}\,) \ . \tag{7}$$

Thus, the dielectric constant of the vacuum plays the role of a variable refractive index under conditions in which vacuum polarizability is assumed to change in response to GR-type influences.

B. Energy in a Vacuum of Variable Polarizability

As will be made explicit in the detailed derivations later, the PV treatment of GR effects is based on the use of equations that hold in special relativity, but with the modification that the velocity of light c in the Lorentz transformations and elsewhere is replaced by the velocity of light in a medium of variable refractive index, c/K, as given in the previous section. Expressions such as $E = mc^2$ are still valid, but now take into account that $c \to c/K$, and E and m may be functions of K, and so forth.

With regard to expressions for energy, Dicke has shown by application of a limited principle of equivalence that the energy of a system whose value is E_o in flat space $(K = 1)$ takes on the value

$$E = \frac{E_o}{\sqrt{K}} \tag{8}$$

in a region where $K \neq 1$ [3]. This is due to that fact that the self-energy of a system changes in response to changes in the local vacuum polarizability. This is analogous to the change in the stored energy of a charged air capacitor during transport to a region of differing dielectric constant.

The energy relationship given by Eq. (8) also implies, via $E_o = m_o c^2$, which becomes $E(K) = m(K)(c/K)^2$, a corollary change in mass

$$m = m_o K^{3/2} \quad , \tag{9}$$

again a consequence of the change in self-energy.

C. Rod and Clock (Metric) Changes in a Vacuum of Variable Polarizability

Another consequence of the change in energy as a function of vacuum polarizability is a change in associated frequency processes which, by the quantum condition $E = \hbar\,\omega$ and Eq. (8), takes the form

$$\omega = \frac{\omega_o}{\sqrt{K}} \quad . \tag{10}$$

This, as we shall see, is responsible for the red shift in light emitted from an atom located in a gravitational potential.

From the reciprocal of Eq. (10) we find that time intervals marked by such processes are related by

$$\Delta t = \Delta t_O \sqrt{K} \quad . \tag{11}$$

Therefore, in a gravitational potential (where it will be shown that $K > 1$) the time interval between clock ticks is increased (that is, the clock runs slower) relative to a reference clock at infinity.

With regard to effects on measuring rods, we note that, for example, the radius of the ground-state Bohr orbit of a hydrogen atom

$$\Delta r_O = \frac{\hbar}{m_O c} \frac{1}{\alpha} \tag{12}$$

becomes (with $c \to c/K$, $m_O \to m$, and α constant as discussed earlier)

$$\Delta r = \frac{\Delta r_O}{\sqrt{K}} \quad . \tag{13}$$

Other measures of length such as the classical electron radius or the Compton wavelength of a particle lead to the relationship Eq. (13) as well, so this relationship is general. This dependence of fundamental length measures on the variable K indicates that the dimensions of material objects adjust in accordance with local changes in vacuum polarizability - thus there is no such thing as a perfectly rigid rod. From the standpoint of the PV approach this is the genesis of the variable metric that is of such significance in GR studies.

We are now in a position to define precisely what is meant by the label "curved space." In the vicinity of, say, a planet or star, where $K > 1$, if one were to take a ruler and measure along a radius vector R to some circular orbit, and then measure the circumference C of that orbit, one would obtain $C < 2\pi R$ (as for a concave curved surface). This is a consequence of the ruler being relatively shorter during the radial measuring process (see Eq. (13)) when closer to the body where K is relatively greater, as compared to its length during the circumferential measuring process when further from the body. Such an influence on the measuring process due to induced polarizability changes in the vacuum near the body leads to the GR concept that the presence of the body "influences the metric," and correctly so.

Of special interest is the measurement of the velocity of light with "natural" (i.e., physical) rods and clocks in a gravitational potential which have become "distorted" in accordance with Eqns. (11) and (12). Let the end points of a measurement be a "true" distance ΔX apart, and let the time for propagation of a light signal from one end point to the other be a "true" time interval ΔT. Since the measurement is assumed to take place in a gravitational potential with a propagation velocity c/K, ΔX and ΔT are related by

$$\frac{\Delta X}{\Delta T} = \frac{c}{K} \quad . \tag{14}$$

However, a rod whose length is Δr_O at infinity will have shortened in the gravitational potential in accordance with Eq. (13), and therefore the *measured* length ΔX_m will be given not by ΔX but by $\Delta X_m = \Delta X \sqrt{K}$. Similarly, a clock whose rate is determined by Eq. (11), and therefore runs slower in the gravitational potential, will yield for a *measured* propagation time $\Delta T_m = \Delta T / \sqrt{K}$. As a result the *measured* velocity of light, v_m, is given by

$$v_m = \frac{\Delta X_m}{\Delta T_m} = \frac{\Delta X \sqrt{K}}{\Delta T / \sqrt{K}} = \frac{c}{K} \bullet K = c\,. \tag{15}$$

We thus arrive at the interesting (and significant) result that the measured velocity of light obtained by the use of physical rods and clocks renormalizes from its "true" value c/K to the value c. The PV formalism therefore maintains the universal constancy of the locally *measured* velocity of light.

D. The Metric Tensor

At this point we can make a crossover connection to the standard metric tensor concept that characterizes the conventional GR formulation. In flat space a (4-dimensional) infinitesimal interval is given by the expression

$$ds^2 = c^2 dt_O^2 - \left(dx_O^2 + dy_O^2 + dz_O^2\right)\,. \tag{16}$$

If rods were rigid and clocks non-varying in their performance in regions of differing vacuum polarizability, then the above expression would hold universally. However, a dx_O-length measuring rod placed in a region where $K > 1$, for example, shrinks according to Eq. (13) to $dx = dx_O / \sqrt{K}$. Therefore, the infinitesimal length which would measure dx_O were the rod to remain rigid is now expressed in terms of the dx-length rod as $dx_O = \sqrt{K}\,dx$. With a similar argument based on Eq. (11) holding for clock rate, Eq. (16) can be written

$$ds^2 = \frac{1}{K} c^2 dt^2 - K(dx^2 + dy^2 + dz^2)\,. \tag{17}$$

Therefore, the infinitesimal interval takes on the form

$$ds^2 = g_{ij} dx^i dx^j\,, \tag{18}$$

where g_{ij} in the above expression defines the metric tensor, and

$$dx^0 = c\,dt,\;\; g_{00} = 1/K,\;\; g_{11} = g_{22} = g_{33} = -K,\;\; g_{ij} = 0 \;\; for\; i \neq j\,. \tag{19}$$

The metric tensor in this form defines an *isotropic coordinate system*, familiar in GR studies.

III. CLASSICAL EXPERIMENTAL TESTS OF GENERAL RELATIVITY IN THE PV MODEL

In the previous sections we have established the concept of the polarizable vacuum and the effects of polarizability changes on metric (rods and clocks) behavior. In particular, we found that metric changes can be specified in terms of a single parameter *K*, the dielectric constant of the vacuum. This is the basis of the PV approach to GR.

In this section we shall explore, with the aid of expressions to be derived in detail in Section IV, specifically how *K* changes in the presence of mass, and the effects generated thereby. The effects of major interest at this point comprise the three classical tests of GR; namely, the gravitational redshift, the bending of light and the advance of the perihelion of Mercury. These examples constitute a good testbed for demonstrating the techniques of the PV alternative to the conventional GR curved-space approach.

For the spherically symmetric mass distribution of a star or planet it will be shown later from the basic postulates of the PV approach that the appropriate PV expression for the vacuum dielectric constant *K* is given by the exponential form

$$K = e^{2GM/rc^2} \ , \tag{20}$$

where *G* is the gravitational constant, *M* is the mass, and *r* is the distance from the origin located at the center of the mass *M*. For comparison with expressions derived by conventional GR techniques, it is sufficient for our purposes to restrict consideration to a weak-field approximation based on expansion of the exponential to second order, viz.,

$$K \approx 1 + \frac{2GM}{rc^2} + \frac{1}{2}\left(\frac{2GM}{rc^2}\right)^2 \ . \tag{21}$$

A. Gravitational Redshift

In a gravitation-free part of space, photon emission from an excited atom takes place at some frequency ω_O, uninfluenced by vacuum polarizability changes. That same emission process taking place in a gravitational field, however, will, according to Eq. (10), have its emission frequency altered (redshifted) to $\omega = \omega_O / \sqrt{K}$. With the first-order correction to $K = 1$ given by the first two terms in Eq. (21), emission by an atom located on the surface of a body of mass *M* and radius *R* will therefore experience a redshift by an amount

$$\frac{\Delta\omega}{\omega_O} = \frac{\omega - \omega_O}{\omega_O} \approx -\frac{GM}{Rc^2} \ , \tag{22}$$

where we take $GM/Rc^2 \ll 1$. Once emitted, the frequency of the photon remains constant during its propagation to a relatively gravitation-free part of space where its frequency can then be compared against that of local emission, and the spectral shift given by Eq. (22) observed.

Measurement of the redshift of the sodium D_1 line emitted on the surface of the sun and received on earth has verified Eq. (22) to a precision of 5% [12].

Experiments carried out on the surface of the earth involving the comparison of photon frequencies at different heights have improved the accuracy of verification still further to a precision of 1% [13-14]. In this case, with the two ends of the experiment separated by a vertical height h, the first-order frequency shift is calculated with the aid of Eqns. (10) and (21) as

$$\frac{\Delta\omega}{\omega} \approx \frac{GM}{R^2c^2}h, \tag{23}$$

where M and R are the mass and radius of the earth. This experiment, carried out at Harvard University, required a measurement accuracy of $\Delta\omega/\omega \sim 10^{-15}$ for a height $h = 22.5$ meters. It was accomplished by the use of Mössbauer-effect measurement of the difference between γ-ray emission and absorption frequencies at the two ends of the experiment.

B. Bending of Light Rays

We consider now the case of a light ray passing in close proximity to a massive body, say, the sun. Given that the velocity of light in a gravitational potential is given by c/K, and given that K varies as shown in Eq. (21), the light ray in essence passes through a medium of variable refractive index.

Since K rises in value near the body, there is a corresponding reduction in the velocity of light in that region. Therefore, for a light ray grazing the body, that part of the wavefront closest to the body will, by virtue of its reduced velocity, cause the wavefront to "wheel about" the body, so to speak. As a result the light ray is deflected toward the body. This deflection, in GR terms, yields a measure of "local curvature," while in the PV approach it is interpreted as a measure of the spatially dependent vacuum polarizability.

Quantitatively, the magnitude of the deflection can be calculated as follows, where we use the sun as an example. Since the deflection is small (less than two seconds of arc), small-angle approximations can be used throughout.

As a light ray grazes the sun, the wavefront tilt, and hence the deflection angle, is found by calculating the accumulated difference in wavefront advancement across the ray (transverse to the direction of propagation) due to the slight difference in phase velocity. Since the velocity of light is given by $v_L = c/K$, to first order Eq. (21) yields

$$v_L = c/K \approx c\Big/\left(1+\frac{2GM}{rc^2}\right) \approx c\left(1-\frac{2GM}{rc^2}\right). \tag{24}$$

With the geometry of a grazing ray as shown in Fig. 1(a), Eq. (24) can be written

$$v_L \approx c\left[1-\frac{2GM}{c^2}\frac{1}{\sqrt{(R+\delta)^2+z^2}}\right] \quad . \tag{25}$$

Therefore, the differential velocity across the ray is (for $\delta \ll R$)

$$\Delta v_L \approx \frac{2GM}{c}\frac{R\delta}{\left(R^2+z^2\right)^{3/2}} \quad . \tag{26}$$

Reference to Fig. 1(b) indicates that, as the ray travels a distance $dz \approx c\,dt$, the differential velocity across the ray results in an accumulated wavefront difference Δz given by

$$\Delta z = \Delta v_L dt \approx \frac{2GM}{c^2}\frac{R\delta}{\left(R^2+z^2\right)^{3/2}}\,dz \tag{27}$$

and an accumulated tilt angle

$$d\alpha \approx \tan(d\alpha) = \frac{\Delta z}{\delta} \approx \frac{2GM}{c^2}\frac{R}{\left(R^2+z^2\right)^{3/2}}\,dz \quad . \tag{28}$$

Integrating over the entire ray path from $z=-\infty$ *to* $z=+\infty$ we obtain

$$\alpha \approx \frac{4GM}{Rc^2} \quad . \tag{29}$$

For the sun this gives 1.75 seconds of arc, a value first verified within experimental error by measurements of grazing starlight images made during total eclipses of the sun in 1919. Further confirmation was obtained in the form of deflection by the planet Jupiter of waves from a strong celestial radio source by an amount of 300 microseconds of arc [15].

C. Advance of the Perihelion of Mercury

The third classical test of GR theory involves a prediction of a slight precession (rotation) of the elliptical orbit of a planet or satellite with each orbital revolution. For even the closest planet to the sun, Mercury, however, the advance of the perihelion amounts to only 43 seconds of arc per century, and is therefore an extremely small effect.

Analysis of the perihelion advance in the PV approach exhibits quite explicitly how changes in vacuum properties lead to GR effects. We begin with the standard Lagrangian for a *free* particle [16],

$$L = -mc^2\sqrt{1-\left(\frac{v}{c}\right)^2} \quad , \tag{30}$$

only we note that the mass *m(K)*, given by Eq. (9), and the velocity of light *c(K)*, given by Eq. (7), are now functions of the vacuum dielectric constant *K*,

$$L = -m(K)c(K)^2\sqrt{1-\left(\frac{v}{c/K}\right)^2} = -m_O K^{3/2}\left(\frac{c}{K}\right)^2\sqrt{1-\frac{\left(\dot{r}^2 + r^2\dot{\theta}^2\right)}{(c/K)^2}} \quad . \tag{31}$$

With *K* given by Eq. (20), the above takes the form

$$L = -m_O c^2 e^{-GM/rc^2}\sqrt{1-\frac{\left(\dot{r}^2 + r^2\dot{\theta}^2\right)e^{4GM/rc^2}}{c^2}} \quad . \tag{32}$$

Substitution into Lagrange's general equations of motion

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}}\right) - \frac{\partial L}{\partial q} = 0 \tag{33}$$

then leads to the specific equations of motion

$$\frac{d}{dt}\left(mr^2\dot{\theta}\right) = 0 \quad , \tag{34a}$$

$$\frac{d}{dt}\left(m\dot{r}\right) = -\frac{GMm}{r^2}e^{-4GM/rc^2} + mr\dot{\theta}^2 - \frac{2GMm}{r^2c^2}\left(\dot{r}^2 + r^2\dot{\theta}^2\right) \quad , \tag{34b}$$

where $m = m_O K^{3/2} = m_O \times \exp(3GM/rc^2)$ and, once derivatives are taken, we assume $\sqrt{1-\left(v/c(K)\right)^2} \approx 1$ for nonrelativistic motion.

The solution to Eq. (34a) yields an expression for the angular momentum ℓ,

$$mr^2\dot{\theta} = \ell \quad . \tag{35}$$

Substitution into Eq. (34b), followed by elimination of the variable *t* by means of $d/dt = \dot{\theta}\, d/d\theta,$ then leads to an equation for the planetary trajectory in the *(r,θ)* plane,

$$\frac{d}{d\theta}\left(\frac{1}{r^2}\frac{dr}{d\theta}\right) = -\frac{GMm_O^{\,2}}{\ell^2}e^{2GM/rc^2} + \frac{1}{r} - \frac{2GM}{c^2}\left[\frac{1}{r^2} + \frac{1}{r^4}\left(\frac{dr}{d\theta}\right)^2\right] \quad . \tag{36}$$

With a change of variable to *u = 1/r*, we obtain, finally,

$$\frac{d^2u}{d\theta^2} + u = \frac{GMm_O{}^2}{\ell^2} e^{2GMu/c^2} + \frac{2GM}{c^2}\left[u^2 + \left(\frac{du}{d\theta}\right)^2\right] \ . \tag{37}$$

Taking *exp(2GM/rc*^{2}*) ≈ 1 + 2GM/rc*^{2}, that is, *exp(2GMu/c*^{2}*) ≈ 1 + 2GMu/c*^{2}, we assume a solution of the form

$$u = A(1 + e\cos\gamma\theta) \ , \tag{38}$$

where here *e* is the eccentricity of the orbit (*e = 0.206* for Mercury). This leads to good approximation to an expression for γ of the form

$$\gamma = \sqrt{1 - 6\left(\frac{GMm_O}{\ell c}\right)^2} \approx 1 - 3\left(\frac{GMm_O}{\ell c}\right)^2 \ . \tag{39}$$

For one revolution of the planet in its solar orbit, the second term in Eq. (39) represents a correction to the nonprecessing Newtonian orbit. In particular, it corresponds to a perihelion advance per orbit of

$$\Delta\theta = 2\pi \times 3\left(\frac{GMm_O}{\ell c}\right)^2 = 6\pi\left(\frac{GMm_O}{\ell c}\right)^2 \ , \tag{40}$$

which for the planet Mercury accumulates to the observed value of 43 seconds of arc per century.

From the standpoint of conventional GR theory the predicted and observed perihelion advance constitutes remarkable corroboration of the curved-space concept. From the standpoint of the PV approach such a result can be interpreted as corroboration of the fact that the dielectric constant of the vacuum in the vicinity of mass is modified by the presence of that mass. The epistemological link between the two approaches can be seen in the fact that in neither is gravity treated as a force *per se*. Rather, in both cases the test body is treated as a *free* particle (note the use of a free-particle Lagrangian in the PV approach) whose trajectory is determined "by the metric properties of space itself."

D. Comparison of the Metric Tensors in the GR and PV Approaches

Having shown by specific calculation that the PV approach to the three classical tests of GR reproduces the traditional GR results, we now establish the underlying generality of such correspondence.

In standard textbook treatments of the three classical tests of GR one begins with the Schwarzschild metric, which in isotropic coordinates is written [17]

$$
\begin{aligned}
ds^2 &= g_{ij}dx^i dx^j \\
&= \left(\frac{1-\dfrac{GM}{2rc^2}}{1+\dfrac{GM}{2rc^2}}\right)^2 c^2dt^2 - \left(1+\frac{GM}{2rc^2}\right)^4\left(dr^2 + r^2d\theta^2 + r^2\sin^2\theta d\phi^2\right) .
\end{aligned} \tag{41}
$$

Expanding the metric tensor for small departures from flatness as a Maclaurin series in (GM/rc^2), we obtain

$$
g_{00} = \left(\frac{1-\dfrac{GM}{2rc^2}}{1+\dfrac{GM}{2rc^2}}\right)^2 = 1-2\left(\frac{GM}{rc^2}\right)+2\left(\frac{GM}{rc^2}\right)^2 - \ldots \tag{42}
$$

$$
g_{11} = g_{22} = g_{33} = -\left(1+\frac{GM}{2rc^2}\right)^4 = -\left[1+2\left(\frac{GM}{rc^2}\right)+\ldots\right] . \tag{43}
$$

Similarly, in the PV approach one begins with the exponential metric defined by Eqns. (17) - (20),

$$
\begin{aligned}
ds^2 &= g_{ij}dx^i dx^j \\
&= e^{-2GM/rc^2}c^2dt^2 - e^{2GM/rc^2}\left(dr^2 + r^2d\theta^2 + r^2\sin^2\theta d\phi^2\right) .
\end{aligned} \tag{44}
$$

This, when expanded to the same order as the Schwarzschild metric tensor above for small departures from unity vacuum dielectric constant, yields

$$
g_{00} = e^{-2GM/rc^2} = 1-2\left(\frac{GM}{rc^2}\right)+2\left(\frac{GM}{rc^2}\right)^2 - \ldots , \tag{45}
$$

$$
g_{11} = g_{22} = g_{33} = -e^{2GM/rc^2} = -\left[1+2\left(\frac{GM}{rc^2}\right)+\ldots\right] . \tag{46}
$$

Comparison of Eqns. (45) - (46) with Eqns. (42) - (43) reveals that, to the order of expansion shown, the two metric tensors are identical. Since the three classical tests of GR do not require terms beyond these explicitly displayed, the agreement between theory and experiment is accounted for equally in both the conventional GR and in the alternative PV formalisms [18].

IV. COUPLED MATTER-FIELD EQUATIONS

In the preceding section we have seen that the three classical tests of GR theory, redshift, bending of light rays, and the advance of the perihelion of Mercury, are accounted for in the PV formalism on the basis of a variable vacuum dielectric constant, K. To carry that out we stated without proof that the appropriate mathematical form for the variation in K induced by the presence of mass is an exponential form, which, under the weak-field conditions prevailing in the solar system, can be treated in terms of the series expansion

$$K = e^{2GM/rc^2} = 1 + 2\left(\frac{GM}{rc^2}\right) + \dots \ . \tag{47}$$

In this section we show how the exponential form is derived from first principles, and, in the process, establish the general approach to the derivation of field equations as well as the equations for particle motion. The approach consists of following standard Lagrangian techniques as outlined, for example, in Ref. 16, but with the proviso that in our case the dielectric constant of the vacuum is treated as a variable function of time and space.

A. Lagrangian Approach

As stated earlier, the standard Lagrangian for a free particle is given by the form Eq. (30)

$$L^p = -mc^2\sqrt{1-\left(\frac{v}{c}\right)^2} \ , \tag{48}$$

which, in the presence of a variable vacuum dielectric constant K is modified to Eq. (31) with the aid of Eqns. (7) and (9) to read

$$L^p = -\frac{m_O c^2}{\sqrt{K}}\sqrt{1-\left(\frac{v}{c/K}\right)^2} \ . \tag{49}$$

This implies a Lagrangian *density* for the particle of

$$L_d^p = -\frac{m_O c^2}{\sqrt{K}}\sqrt{1-\left(\frac{v}{c/K}\right)^2}\,\delta^3(\mathbf{r}-\bar{\mathbf{r}}) \ , \tag{50}$$

where $\delta^3(\mathbf{r}-\bar{\mathbf{r}})$ is the three-dimensional delta function that serves to locate the (point) particle at $\mathbf{r} = \bar{\mathbf{r}}$.

Following standard procedure, the particle Lagrangian density can be extended to the case of interaction with electromagnetic fields by the addition of terms involving the scalar and vector potentials $(\Phi, \mathbf{A})$,

$$L_d^p = -\left(\frac{m_O c^2}{\sqrt{K}} \sqrt{1 - \left(\frac{v}{c/K} \right)^2} + q\Phi - q\mathbf{A} \bullet \mathbf{v} \right) \delta^3 (\mathbf{r} - \bar{\mathbf{r}}) \ , \tag{51}$$

where $(\Phi, \mathbf{A})$ are related to the electromagnetic field vectors $(\mathbf{E}, \mathbf{B})$ by

$$\mathbf{E} = -\nabla\Phi - \frac{\partial \mathbf{A}}{\partial t} , \quad \mathbf{B} = \nabla \times \mathbf{A} \ . \tag{52}$$

The Lagrangian density for the electromagnetic fields themselves, as in the case of the particle Lagrangian, is given by the standard expression (see, e.g., Ref. 16), except that again *K* is treated as a variable,

$$L_d^{em} = -\frac{1}{2} \left(\frac{B^2}{K\mu_O} - K\varepsilon_O E^2 \right) \ . \tag{53}$$

We now need a Lagrangian density for the dielectric constant variable *K*, which, being treated as a scalar variable, must take on the standard Lorentz-invariant form for propagational disturbances of a scalar,

$$L_d^K = -\lambda \ f(K) \left[(\nabla K)^2 - \frac{1}{(c/K)^2} \left(\frac{\partial K}{\partial t} \right)^2 \right] , \tag{54}$$

where $f(K)$ is an arbitrary function of *K*. As indicated by Dicke in the second citation of Ref. 3, a correct match to experiment requires that we take $\lambda = c^4/32\pi G$ and $f(K) = 1/K^2$; thus,

$$L_d^K = -\frac{\lambda}{K^2} \left[(\nabla K)^2 - \frac{1}{(c/K)^2} \left(\frac{\partial K}{\partial t} \right)^2 \right] . \tag{55}$$

We can now write down the total Lagrangian density for matter-field interactions in a vacuum of variable dielectric constant,

$$\begin{aligned} L_d = &-\left(\frac{m_O c^2}{\sqrt{K}} \sqrt{1 - \left(\frac{v}{c/K} \right)^2} + q\Phi - q\mathbf{A} \bullet \mathbf{v} \right) \delta^3 (\mathbf{r} - \bar{\mathbf{r}}) - \frac{1}{2} \left(\frac{B^2}{K\mu_O} - K\varepsilon_O E^2 \right) \\ &- \frac{\lambda}{K^2} \left[(\nabla K)^2 - \frac{1}{(c/K)^2} \left(\frac{\partial K}{\partial t} \right)^2 \right] . \end{aligned} \tag{56}$$

B. General Matter-Field Equations

Variation of the Lagrangian density $\delta\int L_d dxdydzdt$ with regard to the particle variables as per standard action principle techniques (Ref. 16) leads to our first important equation, the equation for particle motion in a variable dielectric vacuum,

$$\frac{d}{dt}\left[\frac{\left(m_O K^{3/2}\right)\mathbf{v}}{\sqrt{1-\left(\frac{v}{c/K}\right)^2}}\right]=q(\mathbf{E}+\mathbf{v}\times\mathbf{B})-\nabla\left(\frac{m_O c^2}{\sqrt{K}}\sqrt{1-\left(\frac{v}{c/K}\right)^2}\right) \tag{57}$$

or

$$\frac{d}{dt}\left[\frac{\left(m_O K^{3/2}\right)\mathbf{v}}{\sqrt{1-\left(\frac{v}{c/K}\right)^2}}\right]=q(\mathbf{E}+\mathbf{v}\times\mathbf{B})+\frac{\left(m_O c^2/\sqrt{K}\right)}{\sqrt{1-\left(\frac{v}{c/K}\right)^2}}\left(\frac{1+\left(\frac{v}{c/K}\right)^2}{2}\right)\frac{\nabla K}{K}\ . \tag{58}$$

We see that accompanying the usual Lorentz force is an additional dielectric force proportional to the gradient of the vacuum dielectric constant. This term is equally effective with regard to both charged and neutral particles and accounts for the familiar gravitational potential, whether Newtonian in form or, as in the last section, taken to higher order to account for GR effects. One note of passing interest is the fact that as $m_O \to 0$, but $v \to c/K$, the deflection of a zero-mass particle (e.g., a photon) in a gravitational field is twice that of a slow-moving particle $(v \to 0)$, an important result in GR dynamics.

Variation of the Lagrangian density with regard to the K variable leads to the second equation of interest, an equation for the generation of GR vacuum polarization effects due to the presence of matter and fields. (In the final expression we use $\nabla^2 K=(1/2K)(\nabla K)^2+2\sqrt{K}\nabla^2\sqrt{K}$ to obtain a form convenient for the following discussion.)

$$\begin{aligned}\nabla^2\sqrt{K}-\frac{1}{(c/K)^2}\frac{\partial^2\sqrt{K}}{\partial t^2}=-\frac{\sqrt{K}}{4\lambda}\Bigg\{&\frac{\left(m_O c^2/\sqrt{K}\right)}{\sqrt{1-\left(\frac{v}{c/K}\right)^2}}\left[\frac{1+\left(\frac{v}{c/K}\right)^2}{2}\right]\delta^3(\mathbf{r}-\bar{\mathbf{r}})\\&+\frac{1}{2}\left(\frac{B^2}{K\mu_O}+K\varepsilon_O E^2\right)-\frac{\lambda}{K^2}\left[(\nabla K)^2+\frac{1}{(c/K)^2}\left(\frac{\partial K}{\partial t}\right)^2\right]\Bigg\}.\end{aligned} \tag{59}$$

Thus we see that changes in the vacuum dielectric constant K are driven by mass density (first term), EM energy density (second term), and the vacuum polarization energy density itself (third term). The fact that the latter term corresponds to the energy density of the K variable can be seen by the following argument. We start with the Lagrangian density Eq. (55), define the momentum density as usual by $\pi = \partial L_d^K / \partial(\partial K/\partial t)$, and form the Hamiltonian energy density by standard techniques to obtain

$$H_d^K = \pi\left(\frac{\partial K}{\partial t}\right) - L_d^K = \frac{\lambda}{K^2}\left[(\nabla K)^2 + \frac{1}{(c/K)^2}\left(\frac{\partial K}{\partial t}\right)^2\right] . \tag{60}$$

Again, in passing, of interest is the fact that the energy densities of the EM fields and the K variable enter into Eq. (59) with opposite signs. Therefore, EM field effects can counteract gravitational field effects. This will become more apparent when we examine the so-called "electrogravitic repulsion forces" associated with the Reissner-Nordstrøm solution to Eq. (59).

Eqns. (58) and (59), together with Maxwell's equations for propagation in a medium with variable dielectric constant, thus constitute the master equations to be used in discussing matter-field interactions in a vacuum of variable dielectric constant as required in the PV formulation of GR.

V. STATIC FIELD SOLUTIONS

We bring our tutorial on the PV approach to a close by demonstrating application of the field Eq. (59) to two static field cases with spherical symmetry: derivation of the expression introduced earlier for the gravitational field alone, and derivation of the corresponding expression for charged masses.

A. Static Fields (Gravitational)

In space surrounding an uncharged spherical mass distribution the static solution *($\partial K/\partial t$ = 0)* to Eq. (59) is found by solving

$$\nabla^2\sqrt{K} = \frac{1}{4K^{3/2}}(\nabla K)^2 = \frac{1}{\sqrt{K}}\left(\nabla\sqrt{K}\right)^2 \tag{61a}$$

or

$$\frac{d^2\sqrt{K}}{dr^2} + \frac{2}{r}\frac{d\sqrt{K}}{dr} = \frac{1}{\sqrt{K}}\left(\frac{d\sqrt{K}}{dr}\right)^2 , \tag{61b}$$

where we have used $(\nabla K)^2 = 4K\left(\nabla\sqrt{K}\right)^2$.

The solution that satisfies the Newtonian limit is given by

$$\sqrt{K} = e^{GM/rc^2} \tag{62a}$$

or

$$K = e^{2GM/rc^2} = 1 + 2\left(\frac{GM}{rc^2}\right) + \ldots \quad , \tag{62b}$$

which can be verified by substitution into the equation for particle motion, Eq. (58). We have thus derived from first principles the exponential form of the variable dielectric constant in the vicinity of a mass as used in earlier sections. As indicated in Section III-D, this solution reproduces to appropriate order the standard GR Schwarzschild metric predictions as they apply to the weak-field conditions prevailing in the solar system.

B. Static Fields (Gravitational Plus Electrical)

We now take up the important case of a static metric generated by a mass M with charge Q. Assuming spherical symmetry, we obtain the electric field appropriate to a charged mass imbedded in a variable-dielectric-constant medium,

$$\int \vec{D} \bullet \vec{da} = K\varepsilon_O E 4\pi r^2 = Q \tag{63a}$$

or

$$E = \frac{Q}{4\pi K \varepsilon_O r^2} \quad . \tag{63b}$$

Substitution into Eq. (59) yields

$$\nabla^2 \sqrt{K} = \frac{1}{\sqrt{K}}\left[\left(\nabla\sqrt{K}\right)^2 - \frac{b^2}{r^4}\right] \tag{64a}$$

or

$$\frac{d^2\sqrt{K}}{dr^2} + \frac{2}{r}\frac{d\sqrt{K}}{dr} = \frac{1}{\sqrt{K}}\left[\left(\frac{d\sqrt{K}}{dr}\right)^2 - \frac{b^2}{r^4}\right] , \tag{64b}$$

where $b^2 = Q^2G/4\pi\varepsilon_O c^4$.

The solution to Eq. (64) as a function of charge (represented by b) and mass (represented by $a = GM/c^2$) is given below. Substitution into Eq. (58) verifies that as $r \to \infty$ this expression asymptotically approaches the standard flat-space equations for particle motion about a body of charge Q and mass M.

$$\sqrt{K} = \cosh\left(\frac{\sqrt{a^2 - b^2}}{r}\right) + \frac{a}{\sqrt{a^2 - b^2}}\sinh\left(\frac{\sqrt{a^2 - b^2}}{r}\right) \;, \quad a^2 > b^2 \quad . \tag{65}$$

(For $b^2 > a^2$ the solution is trigonometric.)

Now let us compare these results for the weak-field case with the comparable Reissner-Nordstrøm solution of the conventional GR approach, which in isotropic coordinates is written [19]

$$
\begin{aligned}
ds^2 &= g_{ij}dx^i dx^j \\
&= \left[\frac{1-\left(\frac{a}{2r}\right)^2+\left(\frac{b}{2r}\right)^2}{\left(1+\frac{a}{2r}\right)^2-\left(\frac{b}{2r}\right)^2}\right]^2 c^2dt^2 \\
&\quad -\left[\left(1+\frac{a}{2r}\right)^2-\left(\frac{b}{2r}\right)^2\right]^2\left(dr^2+r^2d\theta^2+r^2\sin^2\theta d\phi^2\right) .
\end{aligned}
\tag{66}
$$

Expanding the metric tensor for small departures from flatness as a Maclaurin series in $(a/r) = (GM/rc^2)$, we obtain

$$
g_{00} = \left[\frac{1-\left(\frac{a}{2r}\right)^2+\left(\frac{b}{2r}\right)^2}{\left(1+\frac{a}{2r}\right)^2-\left(\frac{b}{2r}\right)^2}\right]^2 = 1-2\left(\frac{a}{r}\right)+\left(2+\frac{b^2}{a^2}\right)\left(\frac{a}{r}\right)^2 - \ldots \ , \tag{67}
$$

$$
g_{11} = g_{22} = g_{33} = -\left[\left(1+\frac{a}{2r}\right)^2-\left(\frac{b}{2r}\right)^2\right]^2 = -\left[1+2\left(\frac{a}{r}\right)+\ldots\right]. \tag{68}
$$

The comparable expansion in the PV approach [see Eqns. (18) - (19)],

$$
\begin{aligned}
ds^2 &= g_{ij}dx^i dx^j \\
&= \frac{1}{K}c^2dt^2 - K\left(dr^2+r^2d\theta^2+r^2\sin^2\theta d\phi^2\right),
\end{aligned}
\tag{69}
$$

when expanded by the use of Eq. (65) to the same order as the Reissner-Nordstrøm metric tensor above, yields

$$
g_{00} = 1-2\left(\frac{a}{r}\right)+\left(2+\frac{b^2}{a^2}\right)\left(\frac{a}{r}\right)^2 - \ldots \ , \tag{70}
$$

$$
g_{11} = g_{22} = g_{33} = -\left[1+2\left(\frac{a}{r}\right)+\ldots\right] \ . \tag{71}
$$

Comparison of Eqns. (70) - (71) with Eqns. (67) - (68) reveals that, to the order of expansion shown, the two metric tensors are identical.

We note from Eq. (70) that the sign of the contribution to the metric due to charge (represented by b) is counter to that of mass (represented by a). In the literature this effect is sometimes discussed in terms of an "electrogravitic repulsion" force [20].

VI. DISCUSSION

In overview, we have shown that a convenient methodology for investigating general relativistic (GR) effects in a non-abstract formalism is provided by the so-called polarizable-vacuum (PV) representation of GR. The PV approach treats metric perturbation in terms of a vacuum dielectric function K that tracks changes in the effective permittivity and permeability constants of the vacuum, a *metric engineering* approach, so to speak [21]. The structure of the approach is along the lines of the $TH\varepsilon\mu$ formalism used in comparative studies of gravitational theories. A summary of the important relationships derived here is presented in the accompanying Table.

The PV-derived matter-field Eqns. (58)-(59) are in principle applicable to a wide variety of problems. This short exposition, covering but the Schwarzschild and Reissner-Nordstrøm metrics and the three experimental tests of GR, is therefore clearly not exhaustive. Consideration was confined to cases of spherical symmetry [22], and important topics such as gravitational radiation and frame-dragging effects were not addressed. Therefore, further exploration and extension of the PV approach to specific problems of interest is encouraged, again with cross-referencing of PV-derived results to those obtained by conventional GR techniques to ensure that the PV approach does not generate spurious results.

With regard to the epistemology underlying the polarizable-vacuum (PV) approach as compared with the standard GR approach, one rather unconventional viewpoint is that expressed by Atkinson who carried out a study comparing the two [23]. "It is possible, on the one hand, to postulate that the velocity of light is a universal constant, to define 'natural' clocks and measuring rods as the standards by which space and time are to be judged, and then to discover from measurement that space-time, and space itself, are 'really' non-Euclidean; alternatively, one can *define* space as Euclidean and time as the same everywhere, and discover (from exactly the same measurements) how the velocity of light, and natural clocks, rods, and particle inertias 'really' behave in the neighborhood of large masses. There is just as much (or as little) content for the word 'really' in the one approach as in the other; provided that each is self-consistent, the ultimate appeal is only to convenience and fruitfulness, and even 'convenience' may be largely a matter of personal taste..."

On the other hand, as we have discussed in Section II, from the standpoint of what is actually measured with physical rods and clocks, the conventional approach captures such measurements in a concise, mathematically self-consistent formalism (the tensor approach), despite its somewhat formidable appearance to a neophyte. Therefore, the standard approach is more closely aligned with the positivist viewpoint that underlies modern scientific thought. Nonetheless, the PV model, with its intuitive, physical appeal, can be useful in bridging the gap between flat-space Newtonian physics and the curved-spacetime formalisms of general relativity.

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Table

Metric Effects in the Polarizable Vacuum (PV) Representation of GR

(For reference frame at infinity, K = 1)

Variable	***Determining Equation***	***K≥1 (typical mass distribution, M)***
vel. of light $v_L(K)$	$v_L = c/K$ Eq. (7)	vel. of light < c
mass m(K)	$m = m_o K^{3/2}$ Eq. (9)	effective mass increases
frequency $\omega(K)$	$\omega = \omega_o / \sqrt{K}$ Eq. (10)	redshift toward lower frequencies
time interval $\Delta t(K)$	$\Delta t = \Delta t_o \sqrt{K}$ Eq. (11)	clocks run slower
energy E(K)	$E = E_o / \sqrt{K}$ Eq. (8)	lower energy states
length dim. L(K)	$L = L_o / \sqrt{K}$ Eq. (13)	objects (spaces) shrink
dielectric-vacuum "grav." forces $F_K(K)$	$F_K(K) \;\alpha\; \nabla K$ Eq. (58)	attractive grav. force

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17. Ref. 1, p. 840.

18. For increasingly larger departures from flatness, however, the two approaches, although initially following similar trends, begin to diverge with regard to specific magnitudes of effects. In the PV approach the solutions for the metric tensor are exponential in form; in the conventional GR approach somewhat more complex. This discrepancy has shown up previously in other general curved-space approaches to GR as well. Of special interest is the so-called Einstein-Yilmaz form, in which Einstein's equations are modified by inclusion of the stress-energy tensor of the gravitational field itself on the R.H.S. in addition to the usual matter/field stress-energy. (For a review of the Einstein-Yilmaz formalism, see Y. Mizobuchi, "New theory of space-time and gravitation - Yilmaz's approach," Hadronic Jour. **8**, 193-219 (1985)). The Yilmaz modification yields exponential solutions in the form derived here by means of the PV approach. The Einstein-Yilmaz equations satisfy the standard experimental tests of GR, as well as addressing a number of mathematical issues of concern to general relativists, and are thus under study as a potentially viable modification to the original Einstein form. (See C. O. Alley, "The Yilmaz theory of gravity and its compatibility with quantum theory," in *Fundamental Problems in Quantum Theory: A Conference Held in Honor of Professor John A. Wheeler*, ed. D. M. Greenberger and A. Zeilinger (Vol. 755 of the *Annals of the New York Academy of Sciences*, New York, 1995), pp. 464-475.) Should further work in the development of general relativity lead to acceptance of the Einstein-Yilmaz form as the canonical form, then the PV-derived results would be applicable under strong-field conditions as well.

19. Ref. 1, p. 841.

20 S. M. Mahajan, A. Qadir and P. M. Valanju, "Reintroducing the concept of <<force>> into relativity theory," Il Nuovo Cim. **65B**, 404-417 (1981).

21. H. E. Puthoff, "SETI, the velocity-of-light limitation, and the Alcubierre warp drive: an integrating overview," Physics Essays **9**, 156-158 (1996).

22. However, it is known that the PV-related $TH\varepsilon\mu$ approach is sufficiently general that results obtained for spherically symmetric gravitational fields can be generalized to hold for nonsymmetric conditions as well.

23. R. d'E. Atkinson, "General relativity in Euclidean terms," Proc. Roy. Soc. **272**, 60-78 (1962.

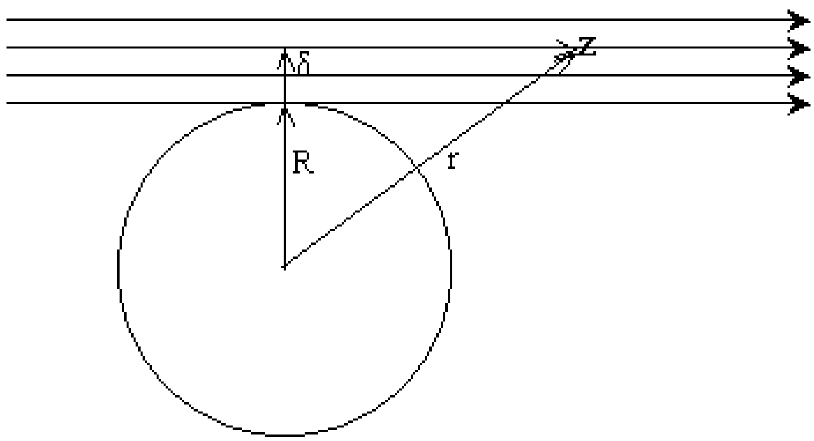


Fig. 1(a)

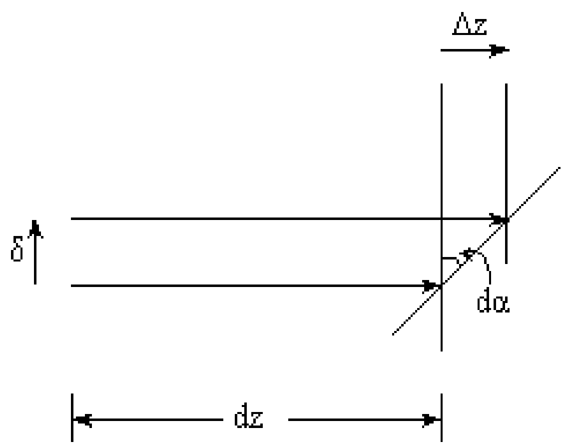


Fig. 1(b)

Fig. 1. Geometry of bending of light rays

“Anti-Gravity Personae”

Yevgeny Podkletnov at the Tampere Lake, Finland

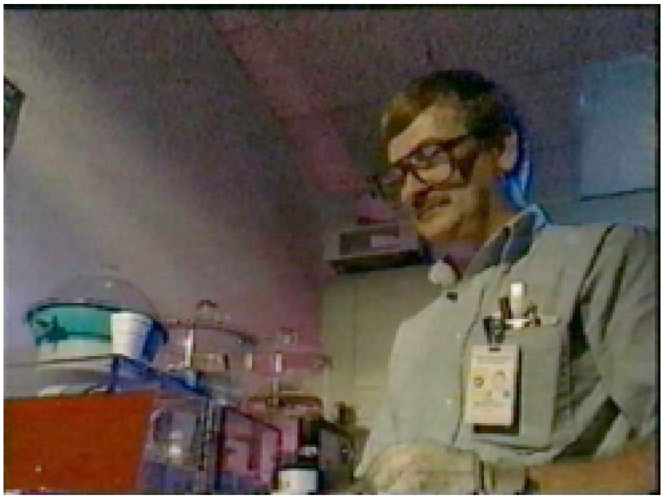
Podkletnov at the Tampere University of Technology

Yevgeny Podkletnov

Dr. Giovanni Modanese

Whitt Brantley - Chief of the Advanced Concepts Office at NASA MSFC

Ron Koczor - Chief Engineer and Project Manager for DeltaG, NASA MSFC

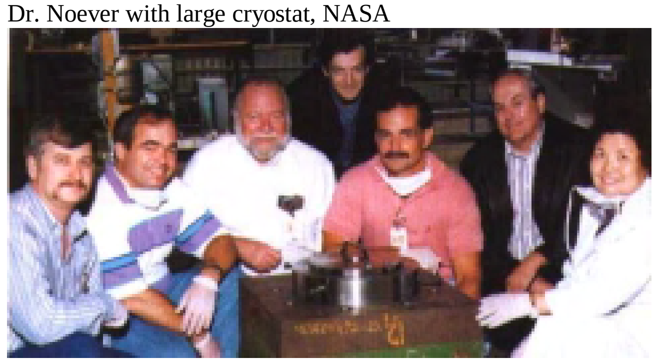


Tony Robertson, Staff Engineer for DeltaG, NASA MSFC

John Schnurer

Dr. Ning Li and two members of the NASA MSFC team, Neil Tyson and Jerald Oakly

Dr. Noever with large cryostat, NASA



NASA team - from left: Tony Robertson, Neil Tyson, Whitt Brantley, David Noever, Jerald Oakly, Ronald Koczor, and Ning Li

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1. ☐ **Accession Number:** 9
Title: Modelling of thermomagnetoelectric effects in type-II superconductors in the mixed state
Author(s): Zhou, Shu-Ang;
First author affiliation: Ericsson Telecom AB ,Stockholm ,Sweden
Serial Title: Physica C: Superconductivity
Abbreviated Serial Title: Phys C Supercond
Volume:v 228
Issue number: n 1-2
Issue date: Jul 10, 1994
ISSN:0921-4534
CODEN: PHYCE6
Publisher: Publ by Elsevier Science Publishers B.V., Amsterdam, Neth
Publication year: 1994
Pages: p 122-128
Abstract: This article presents a phenomenological theory for studying thermomagnetoelectric effects in type-II superconductors in the mixed state. In the theoretical model, the anisotropic effect, the vortex dynamic effect, the flux-flow Hall effect and the thermomagnetic effects in the type-II superconductor in the mixed state are all taken into account self-consistently. It is shown that, at the London approximation, the classical first and second London equations for superconductors in the Meissner state are modified for the superconductors in the mixed state due to vortex dynamic effects, which are, in general, nonlinear. At the linear approximation, effective constitutive equations and field equations are derived to describe the thermomagnetoelectric behavior of anisotropic type-II superconductors in the mixed state. It is shown that the derived field equations are, in general, coupled due to the vortex dynamic effects. A possible solution of a plane thermomagnetic wave in the type-II superconductor in the mixed state is also studied illustratively.
Abstract type: (Author abstract)
Number of references: 27 Refs.
Main heading: Superconducting materials
Controlled terms: Mathematical models; Anisotropy; Hall effect; Thermal effects; Electric field effects; Approximation theory; Equations of state; Nonlinear equations

Uncontrolled terms: Thermomagnetoelectric effects; Phenomenological theory; London approximation; Vortex dynamics effects
Treatment type: Theoretical;
Classification codes: 708.3; 921.6; 931.2; 701.2; 641.1; 701.1
Language: English.
Document type: Journal Articles
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1. ☐ **Accession Number:** 7
Title: Local gravitoelectromagnetic effects on a superconductor
Author(s): Agop, M.;Buzea, C.Gh.;Nica, P.;
First author affiliation: Technical Univ `Gh. Asachi' ,Iasi ,Rom
Serial Title: Physica C: Superconductivity and its Applications
Abbreviated Serial Title: Phys C Supercond Appl
Volume:v339
Issue number: n2
Issue date: Oct, 2000
ISSN:0921-4534
CODEN: PHYCE6
Publisher: Elsevier Science Publishers B.V., Amsterdam, Netherlands
Publication year: 2000
Pages: p 120-128
Abstract: Maxwell's and London's generalized equations, generalized Meissner effect and gravitational shielding in an electromagnetic field are obtained. In such a context, we show that a neutral particle beam in an infinitely thin superconducting cylinder placed in the Earth's gravitoelectric field is focused, and that the penetration depth increases with the pulsation of the electromagnetic field.
Abstract type: (Author abstract)
Number of references: 25 Refs.
Main heading: Superconducting materials
Controlled terms: Gravitational effects; Electromagnetic dispersion; Maxwell equations; Electromagnetic shielding
Uncontrolled terms: Maxwell-London equations; Meissner effects; Gravitoelectromagnetic effects
Treatment type: Experimental;
Classification codes: 708.3; 931.5; 711.1; 701.1; 701.2; 921.2
Language: English.
Document type: Journal Articles
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2. ☐ **Accession Number:** 4133022

Title: Some physical implications of the gravitoelectromagnetic field in fractal space-time theory

Author(s): Agop, M.;Griga, V.;Buzea, C.Gh.;Petreus, I.;Buzea, C.;Marin, C.;Rezlescu, N.;

First author affiliation: Technical `Gh. Asachi' Univ ,Iasi ,Rom

Serial Title: Australian Journal of Physics

Abbreviated Serial Title: Aust J Phys

Volume:v51

Issue number: n1

ISSN:0004-9506

CODEN: AUJPAS

Publication year: 1998

Pages: p 9-19

Abstract: It is shown that in terms of the fractal space-time theory the gravitoelectric potential is responsible for the quantization of the planetary and binary galaxy motions. On a cosmic scale a homogeneous gravitomagnetic field allows not only an ordering of the Universe, but a `global' redshift quantization of galaxies as well.

Language: English.

Document type: Journal Articles

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Feeling Antigravity's Pull

Can NASA stop the apple from falling on Newton's head?

By Adam Rogers

Posted Friday, October 18, 2002, at 8:30 AM PT

"Don't call it antigravity research," Ron Koczor pleads. He's a physicist at NASA's Marshall Space Flight Center in Huntsville, Ala., and he's talking about a project he's been working on for almost a decade. "Call it 'gravity modification.' 'Gravity anomalies.' Anything but antigravity. That's a red flag."

When people find out that the National Aeronautics and Space Administration has researchers working on sci-fi stuff like antigravityâ€"or rather, "gravity modification"â€"the red flags do indeed start waving. Reputable scientists like Koczor earn polite disdain from colleagues (or worse, from funders of research). But truth's truth: NASA has been studying the manipulation of gravity for at least 10 years, as have nongovernment researchers.

NASA began its work after a Russian physicist named Evgeny Podkletnov published an article in the peer-reviewed journal *Physica C* in 1992. Podkletnov claimed that a device built around a superconductor and a magnet could shield an object from gravity. The trick, he said, was to make a superconducting disc about a foot in diameter, chill it, levitate it over magnetsâ€"a nifty property of superconductors is that they repel magnetic fieldsâ€"and set it revolving like a compact disc. Podkletnov said an object placed above that contraption lost 0.3 percent of its weight. The object itself didn't change. Rather, gravity's effect on it lessened.

If that effect could be harnessed and strengthened, the aerospace industry would be upended. Vessels bound for space wouldn't have to ride atop massive, barely controlled explosions. All the energy human beings expend moving things around, from cargo to cars, could be reduced or eliminated. And post-Einsteinian physics would have to be rewritten to explain what the hell was going on. Podkletnov called the effect "gravitational force shielding," and even in the absence of a good theory to explain the phenomenon, other researchers took notice. "Because his experiment and results were published in a peer-reviewed, scientific journal, that gave it a level of credibility," Koczor says.

After Podkletnov published his article, it took NASA until 1999 to figure out how to make a large, thin superconducting disc. Ceramic high-temperature superconductors are brittle as cheap china, and the discs kept shattering. Once they solved that problem, NASA paid Columbus, Ohio-based SCI Engineered Materials $650,000 to build the entire apparatus. But Podkletnov had called for a disc with two layers, one superconducting and one not, and SCI didn't solve that engineering challenge until last year. Then they hit another roadblock. The disc wouldn't spin. SCI engineers stuck a rotor through the

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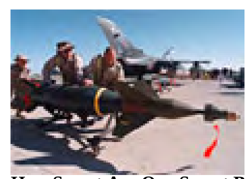

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disc's center to turn it mechanically, but Podkletnov specified 5,000 revolutions per minute. SCI's device barely pulls 30 rpm.

Why not just ask Podkletnov how to build the thing? SCI brought him over to consult a couple of years ago, to little avail. "His excuse basically was that he was a ceramics physicist, not an electrical or mechanical engineer, and other people built the device for him," Koczor says. "Draw your own conclusions. All I know is, if I were a principal investigator on something like this, I would know the size and thread-depth of every screw in the damn thing. But you know, the Europeans and the Russians, they're different. They're much more, 'this is your job and this is my job.' So it's plausible that he didn't know the details." It might not matter. SCI's contract is ending, and Koczor's budget to explore "way-out physics" is spent. He hasn't got the money to actually test the device even if it did meet Podkletnov's specs.

But researchers outside NASA are working on the problem, too. This summer Nick Cook, a writer for *Jane's Defence Weekly*, reported that aerospace giant Boeing was pursuing antigravity research. Boeing denied it. "We are aware of Podkletnov's work on 'anti-gravity' devices and would be interested in seeing further development work being done," said a company statement. "However, Boeing is not funding any activities in this area at this time." Note Boeing's use of the Clintonian present tense. They never contacted *Jane's* to ask for a correction, Cook says. Meanwhile, British aerospace company BAE Systems says it's keeping an eye on the research, and that it had once funded its own antigravity project, Greenglow.

Unfortunately, Cook strains his own credibility somewhat. A couple of weeks after his *Jane's* piece appeared, Cook's book on antigravity research, *The Hunt for Zero Point*, came out. In it, he claims that the Nazis built an antigravity device during World War II. Its absence from present-day science, Cook says, implies a vast "black" world of secret antigravity aircraft that might explain the UFOs people see over Area 51. He's a careful investigative reporter, but once you start talking about UFOs and Nazi antigravity you're not far from hidden tunnels under the White House full of lizard-men disguised as Freemasons.

Even without Nazis, there are plenty of reasons to doubt Podkletnov. My e-mails to the account listed on his recent articles (not peer-reviewed) went unanswered. Even more problematic, I can't find the institution he lists as his affiliation in Moscow. "Eugene always expressed his worries that others could copy his work, although as far as I know he never applied for a patent," Giovanni Modanese, a collaborator of Podkletnov's at the University of Bolzano in Italy, wrote in an e-mail (using a Western version of Podkletnov's first name). "Nonetheless, at the scientific level if one wants a confirmation by others and a successful replication, one must give all the necessary elements." Well, yeah. Modanese says that the current version of the device, now called an "impulse gravity generator," is simpler and could be built "by a big-science team of people expert in superconductivity." A Boeing spokesperson didn't respond to follow-up questions. So, either there's nothing going on here, or it's an X-File.

And the science? Ten years is a long time to go without replication. Combine that with Podkletnov's cagey behavior and it's enough to make even sci-fi geeks like me lose hope. But like the core of any good conspiracy, antigravity research has the ring of plausibility. One of the outstanding problems in physics and cosmology today involves the existence of so-called dark matter and dark energy. They're by far the main constituents of matter in the universe, and nobody knows what they're made ofâ€”researchers have only inferred their existence from gravitational effects. Coming up with a new theory of how gravity works might explain that, though it'd be a scientific revolution on a par with relativity. "Changing gravity is in the cards," says Paul Schechter, an astronomer at MIT. "But so far no one's been able to do better than Einstein." Still, Einstein worked in a lowly patent office. Ron Koczor works for NASA.

Adam Rogers, a reporter for *Newsweek*, is a Knight Science Journalism fellow at the Massachusetts Institute of Technology.

Slate

More brave new world

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The Following is an essay by Paul A. LaViolette, Ph.D.

It is also an excerpt from the book "Electrogravitics Systems: Reports on a New Propulsion Methodology" by Thomas Valone, M.A., P.E.

The U.S. Antigravity Squadron

by Paul A. LaViolette, Ph.D.

Abstract

Electrogravitic (antigravity) technology, under development in U.S.

Air Force black R&D programs since late 1954, may now have been put to practical use in the B-2 Advanced Technology Bomber to provide an exotic auxiliary mode of propulsion.

This inference is based on the recent disclosure that the B-2 charges both its wing leading edge and jet exhaust stream to a high voltage.

Positive ions emitted from its wing leading edge would produce a positively charged parabolic ion sheath ahead of the craft while negative ions injected into it's exhaust stream would set up a trailing negative space charge with a potential difference in excess of 15 million volts.

According to electrogravitic research carried out by physicist T. Townsend Brown, such a differential space charge would set up an artificial gravity field that would induce a reactionless force on the aircraft in the direction of the positive pole.

An electrogravitic drive of this sort could allow the B-2 to function with over-unity propulsion efficiency when cruising at supersonic velocities.

For many years rumors circulated that the U.S. was secretly developing a highly advanced, radar-evading aircraft.

Rumor turned to reality in November of 1988, when the Air Force unveiled the B-2 Advanced Technology Bomber.

Although military spokesmen provided the news media with some information about the craft's outward design, and low radar and infrared profile, there was much they were silent about.

However, several years later, some key secrets about the B-2 were leaked to the press.

On March 9, 1992, "Aviation Week and Space Technology" magazine made a surprising disclosure that the B-2 electrostatically charges its exhaust stream and the leading edges of its wing-like body.(1)

Those familiar with the electrogravitics research of American physicist T. Townsend Brown will quickly realize that this is tantamount to stating that the B-2 is able to function as an antigravity aircraft. "Aviation Week" obtained their information about the B-2 from a small group of renegade west coast scientists and engineers who were formerly associated with black research projects.

In making these disclosures, these scientists broke a code of silence that rivals the Mafia's.

They took the risk because they felt that it was important for economic reasons that efforts be made to declassify certain black technologies for commercial use.

Two of these individuals said that their civil rights had been blatantly abused (in the name of security) either to keep them quiet or to prevent them from leaving the tightly controlled black R&D community. Several months after "Aviation Week" published the article, black world security personnel went into high gear.

That sector of the black R&D community received VERY STRONG warnings and, as a result, the group of scientists subsequently broke off contact with the magazine.

Clearly, the overseers of black R&D programs were substantially concerned about the information leaks that had come out in that article. To completely understand the significance of what was said about the B-2, one must first become familiar with Brown's work.

Beginning in the mid 1920's, Townsend Brown discovered that it is possible to create an artificial gravity field by charging an electrical capacitor to a high-voltage.(2)

He specially built a capacitor which utilized a heavy, high charge-accumulating (high K-factor) dielectric material between its plates and found that when charges with between 70,000 to 300,000 volts, it would move in the direction of its positive pole.

When oriented with its positive side up, it would proceed to lose about 1 percent of it's weight. (3, 4)

He attributed this motion to an electrostatically-induced gravity field acting between the capacitor's oppositely charged plates.

By 1958, he had succeeded in developing a 15 inch diameter model saucer that could lift over 110% of its weight!(5)

Brown's experiments had launched a new field of investigation which came to be known as electrogravitics, the technology of controlling gravity through the use of high-voltage electric charge. As early as 1952, an Air Force major general witnessed a demonstration in which Brown flew a pair of 18 inch disc airfoils suspended from opposite ends of a rotatable arm.

When electrified with 50,000 volts, they circuited at a speed of 12 miles per hour.(6) About a year later, he flew a set of 3 foot diameter saucers for some Air Force officials and representatives from a number of major aircraft companies.

When energized with 150,000 volts, the discs sped around the 50 foot diameter course so fast that the subject was immediately classified.

"Interavia" magazine later reported that the discs would attain speeds of several hundred miles per hour when charged with several hundred thousand volts.(7) Brown's discs were charged with a high positive voltage, on a wire, running along their leading edge and a high negative voltage, on a wire, running along their trailing edge.

As the wires ionized the air around them, a dense cloud of positive ions would form ahead of the craft and corresponding cloud of negative ions would form behind the craft.

Brown's research indicated that, like the charged plates of his capacitors, these ion clouds induced a gravitational force directed in the minus to plus direction.

As the disc moved forward in the response to its self generated gravity field, it would carry with it its positive and negative ion clouds and their associated electrogravity gradient.

Consequently, the discs would ride their advancing gravity wave much like surfers ride an ocean wave. Dr. Mason Rose, one of Townsend's colleagues, described the discs, principle of operation as follows:(8) The saucers made by Brown have no propellers, no jets, no moving parts at all.

They create a modification of the gravitational field around themselves, which is analogous to putting them on the incline of a hill.

They act like a surfboard on a wave...The electrogravitational saucer creates its own "hill", which is a local distortion of the gravitational field, then it takes this "hill" with it in any chosen direction and at any rate. The occupants of one of [Brown's] saucers would feel no stress at all no matter how sharp the turn or how great the acceleration.

This is because the ship and its occupants and the load are all responding equally to the wave like distortion of the local gravitation field. Although skeptics at first thought that the discs were propelled by more mundane effects such as the pressure of negative ions striking the positive electrode, Brown later carried out vacuum chamber tests which proved that a force was present even in the absence of such ion thrust.

He did not offer a theory to explain this nonconventional electrogravitic phenomenon; except to say that it was predicted neither by general relativity nor by modern theories of electromagnetism.

However, recent advances in theoretical physics provide a rather straightforward explanation of the principle. According to the novel physics of subquantum kinetics, gravity potential can adopt two polarities, instead of one. (9-13)

Not only can a gravity field exist in the form of a matter attracting gravity potential well, as standard physics teaches, but it can also exist in the form of a matter repelling gravity potential hill.

Moreover, it predicts that these gravity polarities should be directly matched with electrical polarity; positively charged particles such as protons generating gravity wells and negatively charged particles such as electrons generating gravity hills.

(Thus contrary to conventional theory, the electron produces a MATTER-REPELLING gravity field.

Electrical neutral matter remains gravitationally attractive because of the proton's G-well marginally dominates the electron's G-hill.) Consequently, subquantum kinetics predicts that the negative ion cloud behind Brown's disc should form a matter repelling gravity hill while the positive ion cloud ahead of the disc should form a matter attracting gravity well.

As increasing voltage is applied to the disc, the gravity potential hill and well become increasing prominent and the gravity potential gradient between them increasing steep.

In Rose's terminology, the craft would find itself on the incline of a gravitational "hill".

Since gravity force is known to increase in accordance with the steepness of such a gravity potential slope, increased voltage would induce an increasingly strong gravity force on the disc and would act in the direction of the positive ion cloud.

The disc would behave as if it was being tugged by a very strong gravitational field emanating from an invisible planet sized mass positioned beyond its positive pole.

Emerging Possibilities for Space Propulsion Breakthroughs

Originally published in the Interstellar Propulsion Society Newsletter, Vol. I, No. 1, July 1, 1995.

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The ideal interstellar propulsion system would be one that could get you to other stars as quickly and comfortably as envisioned in science fiction. Before this can become a reality, two scientific breakthroughs are needed: discovery of a means to exceed light speed, and discovery of a means to manipulate the coupling between mass and spacetime. This article explains why these breakthroughs are needed and introduces the emerging possibilities that may eventually lead to these breakthroughs. It should be noted that either of these breakthroughs by itself would have revolutionary consequences which would be of enormous value.

The need to exceed light speed: Simply put, the universe is big. The fastest thing known is light, yet it takes over four years for light to reach our nearest neighboring star. When NASA's Voyager spacecraft left our solar system is was traveling around 37- thousand mph. At that rate it couldn't reach the nearest star until after 80-thousand years. If we want to cruise to other stars within comfortable time spans (say, less than a term in Congress), we have to figure out a way to go faster than light.

The need to manipulate mass and spacetime coupling: This need is less obvious than the light speed issue. The problem is fuel, or more specifically, rocket propellant. Unlike a car that has the road to push against, or an airplane that has the air to push against, rockets don't have roads or air in space. Rockets have to carry along all the mass that they'll need to push against. To circumvent this problem, we need to find a way to interact with spacetime itself to induce propulsive forces without using propellant. This implies that we'll need to find a way to alter a vehicle's inertia, its gravitational field, or its connectivity to the structure of spacetime itself.

Just how limited are rockets for interstellar travel? Although rockets are reasonable for journeys into orbit or to the moon, they become unreasonable for interstellar travel. If you want to deliver a modest size payload, say a full Shuttle cargo (20,000 kg), and you are patient enough to wait 900 years for it to just fly by the nearest star, here's how much propellant you'll need: If you use a rocket like on the Shuttle (Isp~ 500s), there isn't enough mass in the universe to get you there. If you use a nuclear fission rocket (Isp~ 5,000s) you need about a billion super-tankers of propellant. If you use a nuclear fusion rocket (Isp~ 10,000s) you only need about a thousand super-tankers. And if you assume that you'll have a super-duper Ion or Antimatter rocket (Isp~ 50,000s), well now you only need about ten railway tankers. It gets even worse if you want to get there sooner. (Based on mass fractions from ref 1, p. 52) There are other ideas, like using laser pushed light-sails that don't need propellant, but these have limitations. The biggest limitation is their dependence on the laser that remains near Earth. To make an unplanned course change they need to radio back for the laser to track their new course and wait for it to do so. At interstellar distances this is prohibitive. At one light-year from Earth, for example, it would take two years for the command to be sent and the new pointing received.

Is there hope?: Science continues to advance. In addition to the continuing refinements of general relativity and other attempts to better understand mass, space, and time, there have been some recently published theories which provide new perspectives, theories which have been reported in various news articles (Refs 2-6). Each of these theories has some relevance to propulsion and presents new avenues from which to start searching for the breakthrough physics. These recent theories are summarized next.

A theory about "warp drive": Using the formalism of general relativity, it has been shown that faster than light travel may be possible (ref 7). All you need to do is contract spacetime in front of your ship and expand spacetime behind your ship. This "warped" space and the region within it would propel itself "with an arbitrarily large speed" (ref 7). Observers outside this "warp" would see it move faster than the speed of light. Observers inside this "warp" would feel no acceleration as they zip along at warp speed.

So what's the catch? First, to expand spacetime behind the ship you'll need matter having a negative energy density like negative mass, and lots of it too. It is unknown in physics whether negative mass or negative energy densities can exist. Classical physics tends toward a "no," while quantum physics leans to a "maybe, yes." Second, you'll need equal amounts of positive energy density matter, positive mass, to contract spacetime in front of the ship. Third, you'll need a way to control this effect to turn it on and off at will. And lastly, there is the debate about whether this whole "warp" would indeed move faster than the speed of light. To address this speeding issue, the theory draws on the "inflationary universe" perspective. The idea goes something like this: Even though light-speed is a limit within spacetime, the rate at which spacetime itself can expand or contract is an open issue. Back during the early moments of the Big Bang, spacetime expands faster than the speed of light. So if spacetime can expand faster than the speed of light during the Big Bang, why not for our warp drive? Just prior to the publication of the above theory, there was a workshop held at JPL to examine the possibilities for faster-than-light travel (ref 8). Wormholes, tachyons, and alternate dimensions were just some of the topics examined. The conclusions from this informal two-day workshop are as follows: (1) Faster-than-light travel is beyond our current horizons. Not only is the physics inadequately developed, but this physics is not oriented toward space propulsion or toward laboratory scale experiments.

(2) Causality violations (where effect precedes cause) are unavoidable if faster-than-light travel is possible, but it is uncertain whether causality violations are themselves physically prohibited.

(3) A few experimental approaches are feasible to address the science associated with faster-than-light travel, including: (a) Search for evidence of wormholes using astronomical observations: look for a group of co-moving stars or for the visual distortions indicative of a negative mass hole entrance.

(b) Measure the velocity of light inside a Casimir cavity (between closely spaced conductive plates) to search for evidence of negative space energy. This pertains to wormholes, tachyons, and the negative energy density issue.

(c) Resolve the rest mass issue of the Neutrino, determining whether the unconfirmed experimental evidence of imaginary mass is genuine.

(d) Study cosmic rays above the atmosphere, using scattering targets of know composition to look for characteristic evidence of tachyons and more general particle physics events.

New ways to think of inertia and gravity: As mentioned earlier, the ideal interstellar drive would have the ability to manipulate the connection between mass and spacetime. One approach is to look for ways to use electromagnetism, a phenomenon for which we are technologically proficient, to control inertial or gravitational forces. It is known that gravity and electromagnetism are coupled phenomena. In the formalism of general relativity this coupling is described in terms of how mass warps the spacetime against which electromagnetism is measured. In simple terms this has the consequence that gravity appears to bend light, red-shift light and slow time. These observations and the general relativistic formalism that describes them have been confirmed (ref 9, 10). Although gravity's affects on electromagnetism have been confirmed, the possibility of the reverse, of using electromagnetism to affect gravity, is unknown.

New perspectives on the connection between gravity and electromagnetism have just emerged. A theory published in February 1994 (ref 11) suggests that inertia is nothing but an electromagnetic illusion. This theory builds on an earlier work (ref 12) that asserts that gravity is nothing other than an electromagnetic side-effect. Both of these works rely on the perspective that all matter is fundamentally made up of electrically charged particles, and they rely on the existence of Zero Point Energy.

Zero Point Energy (ZPE) is the term used to describe the random electromagnetic oscillations that are left in a vacuum after all other energy has been removed (ref 13). This can be explained in terms of quantum theory, where there exists energy even in the absolute lowest state of a harmonic oscillator. The lowest state of an electromagnetic oscillation is equal to one-half the Planck constant times the frequency. If all the energy for all the possible frequencies is summed up, the result is an enormous energy density, ranging from 1036 to 1070 Joules/m3. In simplistic terms there is enough energy in a cubic centimeter of the empty vacuum to boil away Earth's oceans. First predicted in 1948, ZPE has been linked to a number of experimental observations. Examples include the Casimir effect (ref 14), Van der Waal forces (ref 15), the Lamb-Retherford Shift (ref 10, p. 427), explanations of the Planck blackbody radiation spectrum (ref 16), the stability of the ground state of the hydrogen atom from radiative collapse (ref 17), and the effect of cavities to inhibit or enhance the spontaneous emission from excited atoms (ref 18).

Regarding the inertia and gravity theories mentioned earlier, they take the perspective that all matter is fundamentally constructed of electrically charged particles and that these particles are constantly interacting with this ZPE background. From this perspective the property of inertia, the resistance to change of a particle's velocity, is described as a high-frequency electromagnetic drag against the Zero Point Fluctuations. Gravity, the attraction between masses, is described as Van der Waals forces between oscillating dipoles, where these dipoles are the charged particles that have been set into oscillation by the ZPE background.

It should be noted that these theories were not written in the context of propulsion and do not yet provide direct clues for how to electromagnetically manipulate inertia or gravity. Also, these theories are still too new to have either been confirmed or discounted. Despite these uncertainties, typical of any fledgling theory, these theories do provide new approaches to search for breakthrough propulsion physics. Their utility and correctness remains to be determined.

Another viewpoint on gravity and spacetime: As mentioned earlier, the ideal interstellar drive must not use propellant. Instead the ideal drive would have to use some means to push against spacetime itself. One of the major objections to this notion is the issue of conservation of momentum (ref 19). In order to satisfy conservation of momentum, something must act as a reaction mass. For rockets it is the expelled propellant; for aircraft it is the air. If one considers propelling against spacetime itself, then one must entertain the possibility that the fields of spacetime have an energy or momentum that can serve as a reaction mass. Although existing physics does not provide this perspective, a recent theory has emerged that might. A news article published in December 94 (ref 6) introduced a theory (ref 20) that is challenging Einstein's general theory of relativity. The theory is generating a bit of controversy because it claims that the Einstein field equations need a slight correction. Without this correction it is claimed that the Einstein equations can only predict the behavior of simple one-body problems (where only one gravitating mass exists whose affect on an inconsequential test particle is described). For two-body or n-body problems, this new theory shows that the

Einstein equations are inadequate. The required correction is that another term must be added to the matter tensor, specifically a term for the stress-energy tensor of the gravitational field itself. This suggests that gravitational fields have an energy and momentum of their own. This may be a foundation to address the issue of a reaction mass for the ideal space drive.

Like the previously mentioned theories, it is uncertain whether this theory is correct or not, but it is certain that this theory adds yet another research path to search for breakthrough propulsion.

But wait, there's more: Another avenue to explore pushing against space is to examine the contents of the vacuum that may be indicative of a reaction mass. In addition to the items mentioned above, consider the following phenomena: Cosmic Background Radiation (ref 21), Virtual Pair Production (ref 22), and Dark Matter (ref 23). Whether any of these may constitute a reaction mass or may be evidence for a reaction mass is uncertain.

In addition to these recent events, there have been occasional surveys by the Air Force and others to examine science that may be applicable to propulsion technology (refs 24-29). The options identified by these studies include assessments of the technological status of many popular ideas, such as light-sails, nuclear rockets, and antimatter rockets, plus they include mention of more speculative work. Many of the more speculative ideas, from alternative theories of gravity and electromagnetism through unconfirmed anomalous effects, would be relativity simple to test. Very few of these possibilities have been rigorously investigated.

As you can see, there are a number of dangling loose ends in physics that may prove to be fruitful paths to the goal of creating the breakthroughs for practical interstellar travel. Pick your favorite idea and let us know what you discover.

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Note: Annotations are provided as an aid to the reader and are the personal opinions of the author. No endorsements of the works or ideas presented are implied.

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Paper; Identifies the 3 major objections to the notion of propelling a vehicle by coupling to the properties of space: (1) violates conservation of momentum, (2) no reactive media in space, (3) no grand unified theories to link gravity with other controllable phenomena. Introduces a variety of avenues to possibly satisfy these objections, including introducing the notion of coupling to distant masses via the fundamental structure of the intervening space and the associated need for alternative treatments of space physics.

30.Bennett, G.L. & Knowles, H.B.., (NASA HQ & Physics consulting, El SoBrante, CA 94803), "Boundary Conditions on Faster-Than-Light Transport Systems", AIAA paper 93-1995, presented at the 29th Joint Propulsion Conference, Monterey CA, (1993).

Paper (16 pg); Outlines the prerequisite physics to enable Faster-Than-Light transport: The theory of FTL must equally describe sub-light physics, must not violate causality, must match physics at quantum scales, and must satisfy conservation of energy. The paper discusses Tachyons and Wormholes concluding that it is "very unlikely that interactive tachyons exist";, and the we don't know enough about Wormholes to render judgement. 31. Forward,R.L., (Hughes Research Lab, Malibu CA 90265) "Feasibility of Interstellar Travel: A Review",

In Acta Astronautica, Vol. 14, p 243-252, (1986) Article: Comments on a variety of scientifically plausible propulsion schemes. States that Centauri cluster is reachable within 50 yrs given a velocity of 10% lightspeed, and 25 stars are within reach given 30% lightspeed. Various propulsion schemes are compared, but the comparisons were not on equal footing:

Nuclear Electric Propulsion: 10,000 year trip
Nuclear (Fission) Pulse Propulsion: 130 year trip.

Antimatter Propulsion: 50 year mission requires 9 kg of anti-hydrogen for 1 ton payload.

Nuclear Fusion: To be determined.

Interstellar Ramjet: To be determined, particularly the issue of fusing protons without having to slow them down.

Beamed Power: 20 year trip for a crewed vehicle, but needs lasers that are about 10,000 times more powerful than all the power used on the Earth today.

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Operation LUSTY

The US Army Air Forces' Exploitation of the Luftwaffe's Secret Aeronautical Technology, 1944–45

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Editorial Abstract: The bewildering pace of development in aerospace-power technology immediately following World War II was no accident. The author's account of the highly successful efforts of Army Air Corps leaders to exploit German technology at the end of the war is a story that still has lessons for us today.

IN New World Vistas, the US Air Force's science and technology (S&T) study of 1995, Dr. Gene McCall wrote about the relationship of technology to the Air Force after almost 50 years as an independent service: "It was clear in 1945 that the technology gains of the first half of the twentieth century should be consolidated to create a superior, technology- and capability-based Air Force which could respond to threats not yet imagined. The world which emerged from the destruction of World War II could not have been predicted in 1945, but the emphasis on technology and capability rather than on assumptions about future geopolitical scenarios served us well as we entered the Cold War."[1]

Technology is fundamental to the culture of the US Air Force. For the most part, this technology culture appeared at the same time as the air service itself, due to the nature of heavier-than-air flight. For nearly a century, technological progress has occurred in starts and fits as well as leaps and bounds, exploding geometrically as it accompanied the visionary efforts of key individuals and programs. In conducting analyses of technological efficiencies in anticipation of tomorrow's complex threat environment, one would do well to consider the past successes of some of these key players in technological development. In particular, a seminal turning point occurred on the heels of World War II as part of a plan to exploit German scientific advancements. The plan was called Operation LUSTY (for Luftwaffe secret technology).

Technological change during World War II proceeded at a frightening pace. Developments in aircraft design, propulsion, weap-ons, and electronics contributed vitally to the outcome of events in the global conflict. At the heart of these developments were scientists, largely civilians, who worked to produce military equipment that would turn the tide of the war. Among them was the youthful Hungarian aerodynamicist Dr. Theodore von Kármán. Since his arrival in the United States from Europe, having obtained Guggenheim funding and hoping to avoid rising nationalism and Nazism, he had become acquainted with several Army air officers, among them a young major named Henry "Hap" Arnold, who would later command the US Army Air Forces (AAF) throughout World War II.

Since their first meeting at the California Institute of Technology (Caltech) in the early 1930s, Arnold had witnessed the professor's skilled use of mathematical equations to solve complex aerodynamic problems. After inheriting command of the Army Air Corps in 1938 and driven by a near- obsessive belief in the efficacy of scientific approaches to Air Corps problems, Arnold called civilian scientists to a meeting at the National Academy of Sciences building in Washington, D.C., in 1939. Among the visitors was a team from Caltech, including Kármán. At that meeting, Arnold doled out scientific projects, such as finding a solution to high-altitude windshield icing and developing aircraft radios and jet-assisted takeoff (although the term jet was a misnomer). Kármán assigned the difficult rocket project to his most senior students at Caltech, the "suicide club." From that small project grew what is today the Jet Propulsion Laboratory near Pasadena, California. More importantly, Arnold's trust in Kármán grew as the Caltech program continued to tackle the most difficult projects without hesitation. Arnold did not tolerate a "no-can-do" attitude.

By war's end, General Arnold had decided that the AAF was in a position to capitalize on World War II's many technological developments. He also realized that the United States and its Allies by no means led the world in military aeronautical development. He used his influence with Kármán, convincing him to head a task force of scientists who would evaluate captured German aeronautical data and laboratories for the AAF. As the Allies advanced into Europe during the spring of 1945, Kármán's team, close on the heels of the advancing wave, scoured German laboratories. For the AAF, Operation LUSTY began during a supersecret meeting between General Arnold and Dr. von Kármán on the runway at LaGuardia Airport, New York.[2]

Only after D day and the realization of several key elements in wartime operations did Arnold believe that Allied victory in Europe was a foregone conclusion. The air war had become a deadly routine. At that point, it was merely a numbers game—Allied air strength versus dwindling Axis air capability.

The Normandy invasion occurred under the umbrella of air supremacy. The P-51 had operated successfully with drop tanks for several months with encouraging results. Additionally, B-29 production had increased to acceptable levels. For the operational needs of combat, this long-range, heavy bomber became Arnold's Pacific trump card. He had devoted a great deal of personal effort to ensure its development, despite severe engine problems initially. Only after assuring himself that these production and procurement programs were succeeding did the general set his sights on developing S&T for the AAF.[3]

General Arnold and Dr. von Kármán stayed in "continual conference" after the LaGuardia encounter. Kármán recalled that he was "more impressed than ever with Arnold's vision,"[4] and Arnold insisted that Kármán examine everything and let his "imagination run wild."[5] This challenge fitted perfectly into Kármán's philosophy, including the belief that imagination was a vital part of the invention process.[6] To ensure the excellence of this crucial task, Arnold imposed no completion deadline (a luxury he later rescinded) and insisted that Kármán's group travel to many foreign countries, assess their aeronautics programs, and then fashion a bold final report— a viable forecast for maintaining future American air supremacy.[7] Arnold's establishment of the forecasting group itself was totally secret—almost "cloak and dagger."[8] To accomplish his mission, Kármán officially became an AAF consultant on scientific matters on 23 October 1944.[9]

Kármán's first, unofficial AAF report was organizational in nature, naming as his deputy Dr. Hugh L. Dryden, long-time head of the National Bureau of Standards. November 1944 saw endless conferences and establishment of "relations with the various agencies in the labyrinth of military and scientific aviation."[10] Arnold drafted official, written instructions on 7 November, solidifying the LaGuardia Agreement, a four-page letter that set the boundaries for the report of Kármán's group. They were not very restrictive: "Except perhaps to review current techniques and research trends, I am asking you and your associates to divorce yourselves from the present war in order to investigate all the possibilities and desirabilities for postwar and future war's development as respects the AAF. Upon completion of your studies, please then give me a report or guide for recommended future AAF research and development [R&D] programs."[11] Initially, Kármán's group was called the AAF Consulting Board for Future Research, but apparently AAFCBFR proved too long an acronym, even for the Army. Redesignated the Scientific Advisory Group (SAG) on 1 December 1944, it reported directly to General Arnold.[12]

Germany's last, desperate attempt to end the war at the Bulge occurred as the scientists gathered, anticipating their chance to exploit the work that German scientists had done over the last five to seven years. In January 1945, Kármán's handpicked, scientific team of "thirty-one giant brains" congregated in Washington to begin the monumental task Arnold had given them. Initially, Kármán met internal resistance to a few of his choices for the group—for example, Sir William Hawthorne, an En-glishman. Col Frederick E. "Fritz" Glantzberg, Kármán's military assistant, voiced his objection to having any "foreigners" in the group. Kármán reminded the colonel that Arnold wanted the best people, regardless of their origins. Glantzberg relented, conceding that "the British were, after all, our Allies." Kármán also insisted upon adding a naval officer, William Bollay (a former Caltech student). When the colonel insisted that the professor had gone too far, Kármán responded with the simple question, "But Colonel, the Navy are surely our Allies too?" After considering this for a moment, Glantzberg finally agreed that they were: "Not as close as the British, but a damn sight closer than the Russians."[13] For administrative reasons, neither of these men served in the group until 1949, but Arnold wanted the best and did not care how Kármán carried out that order. Arnold envisioned and enacted the concept of "jointness" long before the term was formalized in the Pentagon almost half a century later with the enactment of the Goldwater-Nichols Department of Defense Reorganization Act.

A five-star general since December 1944, Arnold insisted that the group throw conservative thinking to the wind. Kármán then reminded the scientists in his quiet, broken English that they had to deliver on their promises. Unsurprisingly, the younger members of the team found working in the SAG the "equivalent of a semester of grad school each day."[14] In mid-January 1945, Arnold suffered a severe heart attack and retreated to Florida to recuperate. Fortunately, he had already given Kármán his marching orders.[15]

SAG meetings held during the first weeks in February, March, and April accomplished the basic research and finalized the general format for the report. Kármán emphasized that these spring meetings had a threefold purpose: (1) the SAG would search for ways to secure “scientific insight in a standing Air Force”; (2) it would ensure the continued interest of American scientists in the future of the Air Force; and (3) the group would educate the American public in the necessity of maintaining a strong Air Force.[16] These objectives may have seemed remarkably vague, but specifics in design and engineering were not really part of the SAG’s overall task. Actually, this sweeping view predated America’s entry into the war. In the Pasadena Star News of 24 February 1941, reporters quoted Kármán as saying, “So rapid has been the development of military aircraft during the present war, it is impossible to forecast what performance limits will be obtained by warplanes before the war ends.”[17] For reasons such as this, a broad approach to technology forecasting remained uppermost in Kármán’s mind, and he convinced Arnold of the same.

As mentioned above, in late April 1945, SAG members departed for Europe to inspect liberated enemy laboratories. Operation LUSTY, a name that the cosmopolitan, unmarried young professor sardonically suggested was “unlikely but pleasant,” fulfilled Arnold’s insistence that the SAG investigate the most advanced S&T aeronautical information available worldwide.[18] LUSTY was the code name for a much larger operational, exploitation expedition of European technologies initiated by the US Army, of which the SAG represented only one small part. Arnold’s instructions to Gen Carl “Tooey” Spaatz, commander of US Strategic Air Forces in Europe, were crystal clear: “May I ask . . . in view of the importance of this project that you give it your personal attention.”[19] Already alerted to Arnold’s belief in science, Spaatz did just that. In September 1944, while traveling to the second wartime Quebec Conference, Arnold had informed Spaatz of his belief in the “value and the importance of these long-haired scientists.”[20] Already, Arnold had secretly established the SAG as proof of this commitment. Spaatz’s immediate cooperation was vital to the success of the SAG’s contribution to Operation LUSTY.

After the scientists arrived in Paris on 1 May 1945, one member of the team, H. Guyford Stever, observed the critical nature of timing during the Allied advance. He recalled that, although local looting often presented a problem, the advancing Russians were the real concern. More significantly, Stever mentioned that “until this von Kármán mission, we [scientists] had to piece the enemy’s facts together. Now we had the advantage of actually talking to the German scientists and engineers, seeing their laboratories, and hearing them describe their total programs.”[21] Dr. Dryden echoed Stever’s conclusion: “I think we found out more about what had been going on in the war in a few days [sic] conversations with some of these key German leaders, than all the running around and digging for drawings and models . . . could bring.”[22] Only after Kármán arrived did the group discover the scope of Germany’s S&T efforts.

To preserve that scientific picture, the American teams boxed up everything they could and immediately shipped it to Wright Field, Ohio, the AAF’s center for aeronautical R&D. First on the scene at one location, Navy exploitation teams quickly boxed up the hardware and technical data in large crates and labeled them “US Navy.” Two days later, Army teams made it to the same location, whereupon they crated the Navy boxes in larger crates and relabeled them "US Army."[23] For these reasons—some good, some ridiculous—immediate access to targets became crucial. Spaatz provided the transportation capability to meet these requirements.[24] His personal involvement in the early days of the SAG's visit to Europe helped strengthen his own understanding of its capabilities during his tour as the first chief of staff of the independent Air Force.

Among the discoveries in Germany during the "scientists' invasion" were rocket-propelled fighter planes, radio-controlled bombs, guided antiaircraft missiles, and practically every type of fighter aircraft in the Luftwaffe inventory. The most surprising ones included a jet-powered helicopter built by Doblhoff, swept-back wings hung in high-speed wind tunnels, hidden assembly locations for V-1 and V-2 "vengeance" weapons, and plans for V-3 (intercontinental) rockets capable of reaching targets on the east coast of the United States; many of these rockets were deep below ground in hidden caves. Under the watchful eye of American scientists, including Kármán, German technicians launched several of the V-2 rockets from test sites during the summer and fall months.

Perhaps of even greater significance were thousands of linear feet of data and documents that accompanied these projects—the teams shipped more than 100,000 tons to a London clearinghouse that spring. Upon close examination, many of these German studies confirmed the path that American science had already taken. Some, the jet-powered helicopter for instance (the fourth modification of the original autorotator design), came as a total surprise.[25]

After six weeks of traveling throughout the devastated European countryside, the professor met Arnold—now recovered from his January heart attack—in Paris on 13 July 1945 to discuss the team's initial findings. General Arnold, who was traveling to join President Truman at Potsdam, Germany, and did not have much time, asked the professor to prepare a report that summarized the SAG's discoveries. Kármán submitted Where We Stand on 22 August, satisfying that request.

This summary of the exploitation of German S&T that Kármán's men had unearthed began by listing a set of eight aspects of aerial warfare which, Kármán believed, had become "fundamental realities":

1. Aircraft- manned or pilotless- will move with speeds far beyond the velocity of sound.

2. Due to improvements in aerodynamics, propulsion, and electronic control, unmanned devices will transport means of destruction to targets at distances up to several thousand miles.

3. Small amounts of explosive material will cause destruction over areas of several square miles.

4. Defense against present-day aircraft will be perfected by target-seeking missiles.

5. Only aircraft or missiles moving at extreme speeds will be able to

penetrate enemy territory protected by such defenses.

6. A perfect communication system between fighter command and each individual aircraft will be established.

7. Location and observation of targets; takeoff, navigation, and landing of aircraft; and communication will be independent of visibility and weather.

8. Fully equipped airborne task forces will be enabled to strike at far-distant points and will be supplied by air.[26]

Additionally, the report sought to explain why Germany was more advanced in some areas but lagged in others. The title itself reflected Kármán's evaluation of US posture in regard to foreign scientific developments.

For example, the report did not attribute German achievements in aeronautics to superior scientists but to "very substantial support enjoyed by their research institutions in obtaining expensive research equipment such as large supersonic wind tunnels many years before such equipment was planned in this country."[27] These tunnels supported development in the field of transonic and supersonic wing design to the point of "practical application," whereas advanced design ideas were only at the discussion stage in America, spearheaded by Kármán and others after the Volta Conference of 1935.

Kármán's summary added a warning: "We cannot hope to secure air superiority in any future conflict without entering the supersonic speed range." Additionally, the report stated that "V-2 development was successful not so much because of striking scientific developments [but] because of an early start, military support, and boldness of execution."[28] An early start, unlimited funding, and bold execution of German scientific plans became a recurring theme throughout the report.

However, the United States held substantial leads over the Axis in some areas, such as radar development:

It must be realized that radar is not a facility of attachment which will occasionally be used under bad conditions. Rather, the Air Force of the future will be operated so that radar is the primary facility, and visual methods will only occasionally be used. . . . Hence, in an all-weather Air Force, radar must be the universally used tool for bombing, gunfire, navigation, landing, and control. The whole structure of the Air Force, the planning of its operations, its training program, and its organization must be based on this premise. The development and perfection of radar and the techniques for using it effectively are as important as the development of the jet-propelled plane (emphasis in original).[29]

Today, this realization appears the most prescient of all those made during a period when the AAF's primary doctrine (in Europe certainly)—that of precision, strategic, daylight bombing—was based largely on the ability to acquire the intended target visually.[30] Kármán also pointed out that the Germans had failed to keep stride with the rest of the world because "most of the development took place in industrial laboratories . . . but the very brilliant group of German physicists in universities were never called in to participate. Consequently, while engineering design was good, imaginative new thinking was lacking." Kármán could detect the absence of imagination and individual brilliance—whether in his students or in notable scientists. Further, he predicted that "the ability to achieve Air Force operations under all conditions of darkness and weather contributes more than any other single factor to increasing the military effectiveness of the air forces. Hence, any research program designed to overcome the limitations to flight at night and in bad weather will pay big dividends." Aware of the rapid improvements in radar technology, the professor suggested that the Air Force "be alert in swiftly utilizing any new developments."[31]

By emphasizing radar, Kármán also indirectly assured that the Massachusetts Institute of Technology (MIT) would share in future military research projects. During the war, the MIT Radiation Laboratory led the development of American radar. Generally, just as Caltech held the reins of AAF aeronautical science, so did MIT direct AAF radar programs. In fact, the addition of Dr. Edward Bowles to Arnold's staff in 1943 linked radar and electronic programs to the AAF, much as Kármán's association had linked aeronautics in earlier years. The rivalry that developed between these schools was friendlier than Caltech's rivalry with the National Advisory Committee for Aeronautics (NACA). Both schools held particular expertise in different areas of technological development, and, for the most part, each respected the other's accomplishments.[32]

After publication of this initial report, Kármán began the arduous task of compiling the SAG's detailed work. Suddenly, the deliberate pace normally associated with scientific research was replaced by a great sense of urgency to complete the project. Fearing radical budget cuts at war's end, Arnold cabled Kármán, still in Europe, wondering if the report might be finalized by 15 December 1945. To accommodate the general's request, Kármán canceled an inspection of Japanese aeronautical laboratories (which he had helped to establish at Kobe in 1927) and sent a few of his team members to the Orient instead. From October through December, work proceeded at a frenetic pace. After many sleepless nights, Kármán had the draft version of the final report, Toward New Horizons, delivered to Arnold's desk on 15 December 1945.[33]

Kármán's summary volume, Science: The Key to Air Supremacy, introduced the classified 12-volume report.[34] In essence, this volume amplified the tenets of the August report with a few significant additions. It addressed the problems associated with "research and development from the point of view of the technical requirements which the Air Force must meet in order to carry out its task, securing the safety of the nation." The third chapter elaborated upon correcting the organizational and administrative problems addressed in Where We Stand. Most notable of these was a plea for government authority to "foster," not "dictate," basic research.[35] This long-range, extremely detailed study was the first of its kind in American military history. Along with Where We Stand, it would serve as the blueprint for building the Air Force during the next two decades.

General Arnold was so interested in the possibilities of future airpower development that, based upon Kármán's preliminary report, he offered his personal perceptions of the SAG's importance to General Spaatz. Arnold reminded Spaatz, his successor, that the AAF had no great scientists in its ranks. Military R&D labs had stagnated during the war, largely due to increased production requirements and personnel shortages. The AAF had required civilian help during the war to solve aircraft power-plant and structural-design problems. Only with civilian assistance had the service been able to realize its S&T potential. Arnold reminded Spaatz that "these men did things that the average Army officer could never have accomplished. We must not lose these contacts."[36] Today, through organizations such as the Scientific Advisory Board (SAB), the Air Force continues this tradition through a variety of contacts in civilian industry and academia.

Spaatz took Arnold's advice to heart and established the SAB as a permanent group; it met for the first time on 17 June 1946. It was not, however, attached to the commanding general, as Kármán had suggested, but was relegated to Gen Curtis E. LeMay, deputy chief of the Air Staff for R&D.[37] Nevertheless, the SAB survived postwar cuts by providing scientific advice to higher levels of Air Force leadership. The imperfection of the new system was eventually repaired.

The Arnold/Kármán team, although it existed officially only from November 1944 to February 1946, created the plan that has since evolved into the S&T infrastructure of today's Air Force. Gen Bernard Schriever, father of the Air Force's missile program, once said of Arnold, "There's no question, his greatness was that he created the infrastructure. He visualized the kind of infrastructure that the Air Force needed to really get into the technology age."[38]

In addition to the SAG, Arnold established Project RAND and the Office of Scientific Liaison and funded dozens of guided-missile programs before postwar demobilization and inevitable budget cuts slowed the procedure. Kármán and the SAG assumed the strenuous task of traveling the world in search of the most advanced technologies, constantly mindful of how these advances might be applied to American airpower. In the end, Arnold's recognition of the need for such a study and Kármán's unique ability to apply scientific findings to the practical, technological needs of the Air Force — helped along by lifelong associates at opportune times and places—produced a report that had great potential for long-term success.

Such success, however, carried no guarantees. Initially, funds were scarce, and leadership was in constant flux. The reorganization of the National Military Establishment into the Department of Defense only added to the quagmire. Somehow, by the nature of his association with both officers and scientists, Kármán prevented the newly formed SAB from stalling. He nurtured its structure and function in the face of misunderstandings, opposing agendas, and, at times, lack of interest until the board was capable of independent growth. By 1954, a decade after the process began, Kármán's vision-guided by his own perseverance- proved directly responsible for sustaining the SAB. Yet, Arnold's ghost was never far away. During this period, the general's lifelong associations with officers, industrialists, and scientists continually surfaced. Such people as General Schriever, Lt Gen Laurence Craigie, Lt Gen Benjamin Chidlaw, Larry Bell, Donald Douglas, and Dr. Bowles were all vital to the eventual institutionalization of Toward New Horizons.

Only after Kármán was certain that the SAB would thrive did he resign his chair. Similarly, just as Arnold's influence continued to be felt, so did Kármán's. Former students, colleagues, and friends who had been educated by or employed with the professor carried his broad-based, practical- applications approach to problem solving as part of their own methodology—in several cases, into the mid-1990s. Arnold's drive and Kármán's method, embodied in the institutionalized SAB, had become the Air Force's foundation for S&T matters.

Airpower institutions have evolved erratically since World War I. In Ideas and Weapons, I. B. Holley concluded that "the postwar [World War I] Air Service made use of only a relatively small portion of the experience of the war regarding the problem of weapons."[39] One lesson learned, however, was that quality was preferable to quantity as far as weapons were concerned. Arnold had internalized that lesson. Unfortunately, administrative organizations that might have assured high-quality weapons development during those years had been neglected. Another lesson learned—perhaps the most significant one—concerned unity of command. According to Holley, "the available evidence shows that after the war the Air Service learned the importance of organization for decision and established channels of command for unified, decisive, and authoritative action in contrast to the dispersed, ill-defined, and overlapping channels that existed during the war."[40] This very development allowed Arnold to act as a stopgap, ensuring that the lessons of the Great War had not fallen on totally deaf ears. Arnold acted as the AAF's tangible link between the lessons of World War I and the institutionalization of S&T that became reality after World War II. Ordering the blueprint that became the S&T cornerstone of American airpower is one of Arnold's legacies—creating it is one of Kármán's.

As hundreds of American military soldiers and CIA operatives rummage through caves in war-torn Afghanistan in search of enemy documents and leaders, we are reminded that we have accomplished similar missions before. The intelligence retrieved during Operation LUSTY was part of the process by which the US Air Force entered its technological infancy. Over the past 60 years, developing air and space technology has created the means to improve the human condition or to bring devastating destruction to unsuspecting enemies anywhere in the world. Lines have become blurred between military and civilian aviation and space technology, just as it is difficult to distinguish among those who utilize these technologies for their own purposes.

Today, it remains clear that technology developments made during the twentieth century should be consolidated to create a superior technology- and capability-based twenty-first-century Air Force that will be able to respond to threats not yet imagined. What is unclear is the kind of world that is emerging from the rubble of the World Trade Center and Pentagon. The emphasis placed upon technology and capability that has been the hallmark of the Air Force over the past half century must be molded more and more by future geopolitical scenarios.

As much as ever before in Air Force history, national aerospace power faces difficult challenges in its quest to achieve desired effects against complex, ruthless, and elusive enemies both at home and on foreign soil. Fortunately, because of the efforts of people like Arnold and Kármán, the Air Force now has many technological tools that contribute to achieving national-security objectives and attaining global stability. Today's perceived technological superiority is forcing the Air Force and the nation to reassess how best to apply these technologies during the uncertainties already developing during this new millennium.

Notes

1. Gene H. McCall and John A. Corder, New World Vistas: Air and Space Power for the 21st Century: Summary Volume (Washington, D.C.: Scientific Advisory Board, 1995), iii. For an examination of the technological culture of the Air Force, see Carl H. Builder, The Icarus Syndrome: The Role of Air Power Theory in the Evolution and Fate of the U.S. Air Force (New Brunswick, N.J.: Transaction Publishers, 1994). See also my article "New World Vistas: Looking toward the Future, Learning from the Past," Aerospace Power Journal 13, no. 4 (Winter 1999): 67–76. The author wishes to thank the USAF Historical Research Agency and Air University Press, both at Maxwell AFB, Ala., for their support early in the development of this article.

2. The LaGuardia meeting holds a quiet, yet legendary, place in the history of the Air Force's S&T development. In his later years, Kármán recalled the meeting but not the details. Arnold's plane arrived, jostled by the rough winds of a passing cold front, and Kármán, recovering from recent abdominal surgery, was transported by Army staff car to the end of the runway, where the general joined him after deplaning. Arnold dismissed the military driver and then, in total secrecy, discussed his plans for Kármán and his desires for the exploitation project. Arnold spoke of his concerns about the future of American airpower, and he wondered how jet propulsion, radar, rockets, and other "gadgets" might affect that future. "Vhat do you vish me to do?" Kármán asked with a thick Hungarian accent. "I want you to come to the Pentagon and gather a group of scientists who will work out a blueprint for air research for the next 20, 30, perhaps 50 years," Arnold replied. After promising to give all of the orders on Kármán's behalf (the professor insisted on that caveat), Arnold hopped back in his plane, the deal done. Kármán, flattered and excited, was impressed that General Arnold had the vision to look beyond the war, seeking the help of university scientists. The timing of Arnold's request was not accidental. See Theodore von Kármán with Lee Edson, The Wind and Beyond: Theodore von Kármán, Pioneer in Aviation and Pathfinder in Space (Boston: Little, Brown, 1967).

3. Wesley Frank Craven and James Lea Cate, eds., The Army Air Forces in World War II, vol. 6, Men and Planes (1955; new imprint, Washington, D.C.: Office of Air Force History, 1983), 218–19.

4. Kármán, The Wind and Beyond, 267–68; and Clark Millikan to William Knudsen, letter, 3 October 1944.

5. Gen H. H. Arnold to Gen Carl Spaatz, letter, 6 December 1945; and Arnold to Gen Ira C. Eaker, letter, 22 May 1945, both located in the Hap Arnold Murray Green Collection, USAF Academy Library, Special Collections (hereinafter MGC). See also Craven and Cate, vol. 6, 234; and Thomas A. Sturm, USAF Scientific Advisory Board: Its First Twenty Years, 1944–1964 (Washington, D.C.: USAF Historical Division Liaison Office, 1967), 37.

6. "Disney Folder," Kármán Papers, California Institute of Technology, no. 59.2.

7. Henry H. Arnold, Global Mission (New York: Harper and Brothers, 1949), 532–33, reinforced by a cable sent to Spaatz toward the end of the war, 15 April 1945, in MGC.

8. On 25 October, in a reply to a letter from Lt Gen George Kenney concerning future

planning, Arnold detailed more than 30 specific actions pertaining to aircraft production and design, but he did not mention the Kármán project, already under way. Arnold added only a brief clue in a postscript: "There is still more that is being prepared now but will not be actuated until the Post-War Period." In a speech to the Aeronautical Research Laboratory of the National Advisory Committee for Aeronautics (NACA) on 9 November 1944, Arnold cryptically told the gathering of scientists and engineers that when the AAF got stuck in a development problem or when it looked toward the future of aeronautics, "normally we go to the NACA and ask you people to do that work for us." But Arnold would not go to the NACA this time. Just as he had secretly given the Whittle jet-engine-development problem to the Bell/ General Electric team in 1941, he now gave the critical task of forecasting the requirements for obtaining future air supremacy to Kármán and his scientists.

9. Scientific Advisory Board (SAB) Office, 1944–1945 file, Pentagon, Washington, D.C.

10. Kármán's first report for the Scientific Advisory Group (SAG), 23 November 1944, in MGC; Kármán to Clark Millikan, letter, 4 November 1944, Kármán Papers, California Institute of Technology, no. 73.6; and Michael H. Gorn, The Universal Man: Theodore von Kármán's Life in Aeronautics (Washington, D.C.: Smithsonian Institution Press, 1992), 99.

11. Arnold to Kármán, letter, subject: Instructions for Forecasting Group, 7 November 1944, SAB Office, 1944–1945 file, Pentagon, Washington, D.C.

12. SAB Office, Pentagon, Washington, D.C.; Kármán's first report for the SAG, 23 November 1944, MGC, ref. L/C box 79; Gorn, 99–100; H. H. Arnold Papers, Headquarters Office Instruction 20-76, MGC, L/C box 40; and Arnold to Kármán, letter, 7 November 1944, SAB Office, Pentagon, Washington, D.C.

13. Kármán, The Wind and Beyond, 269–70; and William Rees Sears, Stories from a Twentieth Century Life (Stanford, Calif.: Parabolic Press, 1993), 219.

14. Kármán, interviewed by Shirley Thomas, cassette tape, University of Indiana Library, 1960; T. F. Walkowicz, "Von Kármán's Singular Contributions to Aerospace Power," Air Force Magazine, May 1981, 60–61; and Gorn, 47.

15. Arnold to Lois Snowden, letter, 22 February 1945, MGC. The general described his condition to Lois, his daughter, in mechanical terms: "Apparently one of my cylinders blew a gasket and I had to get down here to have an overhaul job done. . . . While I was here they checked my lubrication, ignition, and gasoline system and they said they were working alright."

16. Sturm, 5.

17. "No Way to Predict Future of Warplane Performance," Pasadena Star News, 24 February 1941, Kármán Papers, California Institute of Technology, no. 157.2.

18. Kármán, transcript of oral history interview, n.d., US Air Force Academy Library, Colorado Springs, Colo.; Chester Hasert, National Academy of Sciences, Washington, D.C., interviewed by author, 10 November 1994; and Operation LUSTY folder, Air Force Historical Research Agency, Maxwell AFB, Ala.

19. Lt Gen Barney Giles (for Arnold) to Spaatz, letter, 19 April 1945, Kármán Papers, California Institute of Technology, no. 90.2; Kármán, The Wind and Beyond, 272; Gorn, 103–5; and Kármán, oral history interview.

20. In a reply to an earlier letter praising radar developments, Arnold wrote Spaatz on 12 September 1944, affirming his trust in scientists, MGC, roll 12.

21. H. Guyford Stever, Washington, D.C., interviewed by author, 18 May 1995.

22. Hugh L. Dryden, Columbia University Oral History Review, 24.

23. Dr. Homerjoe Stewart, Pasadena, Calif., interviewed by author, 21 July 1995.

24. Stever interview. Dr. Stever was working with the British radiation laboratory as part of the MIT exchange team when LUSTY operations began. He was attached to Kármán's group in place of Dr. L. DuBridge, who was unavailable. Stever is a former chairman of the SAB from 1962 to 1964 and a former presidential science advisor.

25. Ibid.; Dr. Richard P. Hallion, interview for New World Vistas, videotape, Office of Air Force History, Bolling AFB, Washington, D.C.; summary of memo from Kármán to Arnold, 30 July 1945, which documented the group's travels to that point, MGC, roll 12; and "History of Operation Lusty, 6 June 1944–1 February 1945," US Air Force Historical Research Agency, Maxwell AFB, Ala., file 570.650A.

26. Theodore von Kármán, "Where We Stand: First Report to General of the Army H. H. Arnold on Long Range Research Problems of the Air Forces with a Review of German Plans and Developments, 22 August 1945," typed manuscript (Wright-Patterson AFB, Ohio: Air Force Materiel Command History Office, August 1945), 1–2. Sturm's USAF Scientific Advisory Board: Its First Twenty Years includes the evolution and decline of the group through 1964. Alan Gropman has nicely summarized the report itself in "Air Force Planning and the Technology Development Planning Process in the Post–World War II Air Force- The First Decade (1945–1955)," in Military Planning in the Twentieth Century: The Proceedings of the Eleventh Military History Symposium, USAFA, 10–12 October 1984 (Washington, D.C.: Office of Air Force History, 1986), 154–230. Kármán's reports may be found in the appendices of my book Architects of American Air Supremacy: Gen. Hap Arnold and Dr. Theodore von Kármán (Maxwell AFB, Ala.: Air University Press, 1997), the only publication in which the Kármán reports are published together and in their entirety.

27. Kármán, Where We Stand, 5.

28. Ibid., 8, 12, 21.

29. Ibid., 75–76.

30. Maj Gen Haywood Hansell Jr., to author, letter, 4 October 1979. Although the AAF did accomplish a limited number of area-bombing missions in Europe, these were supplemental to precision attacks in almost every case.

31. Daso, Architects of American Air Supremacy, 283–85.

32. Jack H. Nunn, "MIT: A University's Contribution to National Defense," Military Affairs, October 1979, 120–25.

33. Kármán, The Wind and Beyond, 290; and Gorn, 113–14.

34. Theodore von Kármán, Science: The Key to Air Supremacy, summary vol. to Toward New Horizons: A Report to General of the Army H. H. Arnold, Submitted on Behalf of the A.A.A. Scientific Advisory Group (Wright Field, Dayton, Ohio: Air Materiel Command Publications Branch, Intelligence, T-2, 15 December 1945), 1.3.

35. Kármán, Toward New Horizons, commemorative version (Wright-Patterson AFB, Ohio: Headquarters Air Force Systems Command History Office, 1992), 69–84. Although future attempts were made to repeat the forecast, none made such a monumental impact on the structure or the vision of the US Air Force. Originals of the Kármán report are located in both the Arnold Papers and Spaatz Papers in the Library of Congress as well as at the Air Force Materiel Command Archives at Wright-Patterson AFB, Ohio.

36. Arnold to Spaatz, letter, 6 December 1945, MGC.

37. Sturm, 14–15.

38. Bernard A. Schriever, Washington, D.C., interviewed by author, 10 November 1994.

39. I. B. Holley Jr., Ideas and Weapons: Exploitation of the Aerial Weapon by the United States during World War I: A Study in the Relationship of Technological Advance, Military Doctrine, and the Development of Weapons (1953; new imprint, Washington, D.C.: Office of Air Force History, 1983), 176. The following discussion is based on Dr. Holley's summary and conclusions.

40. Ibid., 177.

Contributor

Dik Alan Daso (USAFA; MA, PhD, University of South Carolina) is curator of modern military aircraft at the Smithsonian Institution, National Air and Space Museum, Washington, D.C. During his career in the Air Force, his assignments included T-38 pilot instructor training at Randolph AFB, Texas; RF-4C instructor pilot; F-15 pilot; and chief of Air Force doctrine at Headquarters Air Force, the Pentagon. Daso is the author of Architects of American Air Supremacy: Gen. Hap Arnold and Dr. Theodore von Kármán (Maxwell AFB, Ala.: Air University Press, 1997) and Hap Arnold and the Evolution of American Airpower (Washington, D.C.: Smithsonian Institution Press, 2000), winner of the American Institute of Aeronautics and Astronautics Manuscript Award in 2001.

Disclaimer

The conclusions and opinions expressed in this document are those of the author cultivated in the freedom of expression, academic environment of Air University. They do not reflect the official position of the U.S. Government, Department of Defense, the United States Air Force or the Air University.

RS Electrogravitic References

(source: http://www.padrak.com/ine/RS_REF1)

"This file contains an electrogravitics reference list, copied ad hoc from various other files and sources, with commentary by yours truly.

Prepared by: Robert Stirniman (robert@skylink.net)

This Update: March 1, 1996

[Email address updated: Dec. 23, 1997].

Danger Will Robinson! Some of the following information is serious, and some is nonsense. Some of the things that might at first seem to be nonsense, are not. And some things referenced below, which come from serious credentialed scientists, are in fact nonsense. Whatever the case, it's been included. Good luck sorting it out.

Understanding gravity is a matter of time.

------------------------ Internet Sites

Elektromagnum web site by David Jonsson: http://nucleus.ibg.uu.se/elektromagnum

KeelyNet:
http://www.protree.com/KeelyNet/

Los Alamos National Lab Physics E-Print Archive: http://xxx.lanl.gov/

Center for Gravitational Physics and Geometry: http://vishnu.nirvana.phys.psu.edu/

Bill Beaty's Weird Science, Anomalous Physics, Free-Energy, Tesla Society: http://www.eskimo.com/~billb/

The Institute For New Energy, Patrick Bailey, homepage : http://www.padrak.com/ine/

Digital Equipment Corp's Alta Vista web search engine.
If you can't find it with this, it ain't out there yet. http://www.altavista.digital.com/

Elsevier Science. Search or browse the table of contents of more than 900 science and technology journals. Data since early 1995. http://www.elsevier.nl/cas/estoc/

Norman Redington's website, The Net Advance of Physics, recent preprints and papers describing new developments in physics: http://pobox.com/~redingtn

Embry-Riddle Aeronautical University's Aerospace Virtual Library: http://macwww.db.erau.edu/www_virtual_lib/aerospace.html

Jack R. Hunt Memorial Library (aerospace): http://amelia.db.erau.edu/

American Institute of Aeronautics & Astronautics (AIAA) home page: http://www-leland.stanford.edu/group/aiaa/national

NASA Langley Research Center Library:
http://blearg.larc.nasa.gov/library/larc-lib.html

NASA Scientific and Technical Information: http://www.sti.nasa.gov/STI-homepage.html

University of Alabama at Hunstville. Dr Ning Li and Dr Douglas Torr. Microgravity research consultants to NASA's Marshall Space Center. http://isl-garnet.uah.edu/RR93/uahmatsci.html

The Microgravity Research Experiments (MICREX) Data Base http://samson2.msfc.nasa.gov/fame/exps/kaw-sl3.html

Interstellar Propulsion Society:
http://www.digimark.net/ips/

National Science Foundation World Wide Web Server.
Find out where your science tax dollars are going. http://stis.nsf.gov/

Nexus magazine web page:
http://www.peg.apc.org/~nexus/

Home page of New Scientist magazine:

http://www.newscientist.com/pstourist/index.html

The Farce of Physics:
http://www.germany.eu.net/books/farce

The World Wide Web Virtual Library: Sumeria/Technology
http://lablinks.com/sumeria/tech.html

The Society for the Advancement of Autodynamics website:
http://www.webcom.com/~saa

Popular Mechanics' Tech Update Article Archive: http://popularmechanics.com/cgi-bin/wais.pl

Fortean web site:
http://www.clas.ufl.edu/anthro/fortpages.html.

Homepage of Apeiron Magazine:
http://montreal.aei.ca:80/~apeiron/

Borderland Sciences Research Foundation ftp site: ftp: northcoast.com/pub/bsrf

Homepage of the International Society of Unified Science, for advancing the Reciprocal System Theory of Dewey B. Larson:
http://infox.eunet.cz/interpres/sr/isus/index.html

Frank Lofaro's homepage, including alternative science links, and two articles by Whittaker written in 1903 and 1904 about scalar field theory and free energy:
http://www.unlv.edu/~ftlofaro/

Homepage of the Oppositely Charged Twin Monopole (OCTM) theory of matter, "Gravity is a Push", US patent number 5,377,936:
http://www.epicom.com/gravitypush

Dr Eujin Jeong's Dipole Theory of Gravity homepage: http://www.realtime.net/~ejeong/

Levesque's (laurent@ee.umanitoba.ca) web site: http://www.ee.umanitoba.ca/~laurent

UFOs and the New Physics:
http://www.hia.com/hia/pcr/ufo.html

There is a fairly large body of evidence which supports the idea of a strong relationship, and possibly an equivalent fundamental source, for electromagnetism and gravitation. Many references to this effect are contained in this resource list. But for now, let's forget about the experimental evidence and theoretical ideas which are presented here, and begin with first principles.

What if our knowledge of physics had evolved differently?

What if no one had ever given a thought to any theory of gravitation, before we discovered the principles and theories of electromagnetics and the two nuclear forces. We might have developed some fairly good theories which unify the "three" forces. We would know that clumps of matter are held together primarily by electromagnetic forces. And we would find experimentally that if we separate some of these clumps of matter, a small force continues to exist which trys to bring them back together. Would it seem rational to speculate that this force is something entirely new and completely different from electromagnetics? Would it not be a great foolishness to invent something new and call it gravity and claim that it has no relationship with the known forces, and then write elaborate mathematical theories which describe it solely as geometry? Or, would it be more rational to see it as what it probably is -- a manifestation of the electromagnetic forces which we already know to hold matter together?

Could it be that electric charge is a fundamental thing, and inertial mass is merely a shadow of something primal, and what we know as a gravitational field is merely the net result of other primary fields? Geometrize it if you find it useful to do so, but please recognize that defining gravity as geometry lends no information to the understanding of its cause.

Of all the forces we know, there is none stronger than a paradigm. -- Robert Stirniman
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GENERAL RELATIVITY & QUANTUM COSMOLOGY, ABSTRACT GR-QC/9512027 From: kldalton@cs.clemson.edu
Date: Tue, 12 Dec 1995 11:30:30 -0500
Author(s): Kenneth Dalton
Journal-ref: Hadronic J. 17 (1994) 483-501
Hypothesis: The electromagnetic field is the source of gravitation. This treatment of gravitation is consistent with the quantum theory of matter, which holds that electric charge (or `generalized charge') is the most fundamental attribute of matter. Experimental predictions of the theory include: (1) any massive body generates a time-dependent gravitational field; (2) there is a linear correlation between the gravitational red-shift of a stellar source and the energy of cosmic rays emitted by that source, given by $ {\Delta \nu}/{\nu_0} = energy (eV)/10^{27} $; (3) the maximum energy of cosmic rays is $ 10^{27} $ eV; (4) this limit is associated with an infinitely red-shifted stellar object, an ``electrostatic black-hole," at the potential $ c^2/G^{1/2} = 10^{27} $ volts. Finally, the theory predicts that the gravitational potential near any charged elementary particle is many orders of magnitude greater than the Newtonian value.

HIGH ENERGY PHYSICS - THEORY, ABSTRACT HEP-TH/9601066 From: Kenichi Horie Date: Sat, 13 Jan 1996 14:41:29 +0900
Geometric Interpretation of Electromagnetism in a Gravitational Theory with Torsion and Spinorial Matter
Author(s): Kenichi Horie (KEK Japan)
Comments: Ph.D. thesis, 98 pages, LaTeX file, ca 276kB Possible geometric frameworks for a unified theory of gravity and electromagnetism are investigated: General relativity is enlarged by allowing for an arbitrary complex linear connection and by constructing an extended spinor derivative based on the complex connection. Thereby the spacetime torsion not only is coupled to the spin of fermions and causes a four-fermion contact interaction, but the non-metric vector-part of torsion is also related to the electromagnetic potential. However, this long-standing relation is shown to be valid only in a special U(1) gauge, and it is a formal consequence of the underlying extended geometry.

Salem, Kenneth G.
The new gravity : a new force, a new mass, a new acceleration : unifying gravity with light / Kenneth G. Salem. 1st ed. Johnstown, PA : Salem Books, c1994. xiii, 181 p. : ill. ; 22 cm.
LC CALL NUMBER: QC794.6.G7 S26 1994
SUBJECTS: Unified field theories. Gravitation. Electromagnetic interactions.
ISBN: 0962539813

Green, James A.
Gravitation & the electroform model : from general relativity to unified field theory / by James A. Green. 7th ed. [Wichita, Kan.] : Greenwood Research, c1994. 33 p. : ill. ; 24 cm.
LC CALL NUMBER: QC178 .G68 1994
SUBJECTS: Gravitation. Unified field theories. Astrophysics. "Wichita State University Physics Graduate Seminar, Dec.1993 and Dec. 1994"

Another very interesting research on anti-gravity is done (and still going on) by the Japanese prof. Shinishi SEIKE. He published his findings in the book " The Principles of Ultra Relativity ". For his highly mathematical (no nonsense) book write to:

Shinichi SEIKE
G Research Institute
Box 33
UWAJIMA/Ehime (798)
JAPAN

Patents for anti-gravity devices and systems have been issued to Brown, Hooper, Wallace, and others.

US Patents Awarded to Townsend Brown --

300,311 T.T.Brown Nov. 15, 1928 A Method of and an Apparatus or Machine for Producing Force or Motion
1,974,483 T.T.Brown Sept. 25, 1934 Electrostatic Motor
2,949,550 T.T.Brown Aug. 16, 1960 Electrokinetic Apparatus
3,022,430 T.T.Brown Feb. 20, 1962 Electrokinetic Generator
3,187,206 T.T.Brown June 1, 1965 Electrokinetic Apparatus
3,296,491 T.T.Brown Jan. 3, 1967 Method and Apparatus for Producing Ions and Electrically-Charged Aerosols
3,518,462 T.T.Brown June 30, 1970 Fluid Flow Control System

Dr. late William J. Hooper, BA, MA, PhD in Physics was affiliated with the University of California at Berkley, and was Professor Emeritus, when he died in 1971. His works are documented and he gained two U.S. patents for his "ALL-ELECTRIC MOTIONAL FIELD GENERATOR". He claimed use of the "Motional Electric Field" to produce gravity and anti-gravity for use in SPACECRAFT and AIRCRAFT. Indeed, in U.S. patent #3,610,971 you can see a Flying Saucer diagram is used as an example in Figure 7.
-- James Hartman, CaluNET Future Science Administrator

US Patent #3,610,971. "All Electric Motional Electric Field Generator", Awarded to William Hooper, April 1969

US Patent # 3,656,013. "Apparatus for Generating Motional Electric Field", Awarded to William Hooper, April 1972

Hooper, W. J. (1974). New Horizons in Electric, Magnetic and Gravitational Field Theory, Electrodynamic Gravity, Inc. 1969

Frances G. Gibson, "THE ALL-ELECTRIC FIELD GENERATOR AND ITS POTENTIAL", Electrodynamic Gravity, Inc., 1983

"Electric Propulsion Study", Dr. Dennis Cravens, SAIC Corp, prepared for USAF Astronautics Lab at Edwards AFB, August 1990 -- Section 3.7 Non-Inductive Coils
Several authors have suggested that v x B term in the Lorentz expression should be called into question. Several unverified experimental results have ever been made. An experiment is suggested to test one or several of these theoretical views. This is an area where the experimental procedure is workable and the outcome could have direct results in the area of inertia forces.
During the late 60's William J. Hooper put forth an interesting theory involving the v x B terms dynamic electrical circuits. There was and is uncertainty as to the exact physical understanding of the Biot-Savart-Lorentz law and Ampere's law involving the set of reaction forces. Peter Graneau has studied these expressions. Hoopers view was that there are three different types of electric fields due to the distribution of electric field, and two due to induction.
At the heart of the issue is the connection of the magnetic field and its source in the charged particles. EM theory is presently consistent with the idea that spinning magnetic dipoles create effects indistinguishable from charged particles. There has been no critical experiment which can disprove whether a magnetic flux rotates with its source. If it does co-move with its source then it is logical to assume that a motional electric field in a fixed reference frame of the current induces a magnetic field. This concept is likewise consistent with a field-free interpretation such as Ampere's original laws.
(with 4 pages more about Hooper's theories)

FREE FALL OF ELEMENTARY PARTICLES: ON MOVING BODIES AND THEIR ELECTROMAGNETIC FORCES, by Nils Rognerud 1994 (nils@ccnet.com) (available at the elektromagnum web site) This paper is a review of the problem of the

observable action of gravitational forces on charged particles. The author discusses the induced electric fields and the sometimes overlooked unique physical properties. He analyzes several experiments, showing the reality of the induced electric fields. The current interpretation, based on the idea of only one electric field, with certain characteristics, is compared with alternative approaches.
The Hooper Coil:
The author has tested a setup by pulsing strong currents, opposite and equal, through multiple parallel conductors. The configuration of the conductors in this type of experiment will cancel the B-fields, while still producing an Em field, in accordance with Eq. 4.2. This is similar to an experiment by Hooper (W. J. Hooper), who successfully predicted and measured the motional electric field - all in zero resultant B-field.
Interestingly, all of the above experiments can influence an electron with a zero B-field, in the region of the electron. This has some profound implications - one of which is that the motional electric force field is immune to electrostatic or magnetic shielding. Experimentally, it can be confirmed that the motional electric field is immune to shielding and follows the boundary conditions of the magnetic (not electric) field. The only way to shield a motional electric field is to use a magnetic shield around the source of the magnetic flux - containing it at the source. These effects are not startling if one remembers that the motional electric field is a magnetic effect and that a magnetic field has a different boundary condition than the electric field.

US Patent #3626605 -- "Method and Apparatus for Generating a Secondary Gravitational Force Field"
Awarded to Henry Wm Wallace of Ardmore PA Dec 14, 1971

US Patent #3626606 -- "Method and Apparatus for Generating a Dynamic Force Field"
Awarded to Henry Wm Wallace of Ardmore PA Dec 14, 1971

US Patent #3823570 -- "Heat Pump" (based on technology similar to the above two inventions)
Awarded to Henry Wm Wallace of Freeport NY July 16, 1973

Gravity is a PUSH!
United States Patent Number 5,377,936
NET KINETIC ENERGY DIFFERENTIAL GUIDANCE AND PROPULSION SYSTEM FOR SATELLITES AND SPACE VEHICLES

In the early 1960s, Erwin Saxl conducted a series of experiments which seemed to illustrate a non-zero coupling between EM and gravitational fields. He claimed to see a change in the period of a torque pendulum when its electric potential was raised.

US Patent # 3357253 -- "Device and Method for Measuring Gravitational and Other Forces", awarded to E.J. Saxl, December 1967

"An Electrically Charged Torque Pendulum", by E.J. Saxl, Nature 203, Page 136, July 11 1963.

US patent number #5,076,971.
Barker places radioactive elements inside the sphere of a Van de Graaff generator, runs it at a negative potential for several minutes/hours/days -- and finds that the rate of radioactive decay is extremely enhanced -- with some relationship to the magnitude of the negative potential.

The principal investigator undertook a series of experiments to test the "Barker effect" and the "Keller Catalytic Process" in changing the rate of radioactive decay of heavy elements (elements heavier than lead, such as radium, thorium, or uranium, all of which are radioactive). Barker claims that subjecting radioactive materials to high electrostatic potentials (50,000 volts to 500,000 volts) can increase or decrease the rate of radioactive decay, with short exposures of the high voltage

capable of inducing erratic decay rates which slowly return to normal over a period of weeks. Keller claims that subjecting radioactive materials to the high heat and fusing reaction of a chemical process (Keller Catalytic Process) can eliminate the radioactivity completely.
-- Michael Mandeville http://www.aa.net/~mwm/dexmrad1.html

Carr, Otis (1959). "Amusement Device," (i.e. A Flying Saucer), US Patent No. 2,912,244.

Otis Carr's work involved counter-rotating charged discs that supposedly produced thrust when they reached a certain speed in relation the the earth's rotational speed and became activated by free energy from space. Maybe he did have something." -- James E. Cox

Carr's work is similar in some respects to Hooper's inventions. In both cases, an anti-gravitational effect is reported to result from equal and opposite electric currents. Furthermore, one of Hooper's embodiments, the pancake coil, has an uncanny resemblance to the gravitational shielding experiments which were recently conducted in Tampere Finland (1992 and 1995). Except that in the Tampere experiments, the equal and opposite current is generated in a superconductor disk by way of the Meissner effect. Will we soon begin to recognize value of the discoveries that Carr made nearly 40 years ago, and Hooper made over 25 years ago? -- Robert Stirniman
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EXPERIMENTAL RESULTS OF HOOPER'S GRAVITY-ELECTROMAGNETIC COUPLING CONCEPT National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH. MILLIS, MARC G. WILLIAMSON, GARY SCOTT JUN. 1995 12 PAGES Presented at the 31st Joint Propulsion Conference and Exhibit, San Diego CA, 10-12 Jul. 1995; sponsored by AIAA, ASME, SAE, and ASEE NASA-TM-106963 E-9719 NAS 1.15:106963 AIAA PAPER 95-2601 Avail: CASI HC A03/MF A01 Experiments were conducted to test assertions from Patent 3,610,971, by W.J. Hooper that self-
canceling electromagnetic coils can reduce the weight of objects placed underneath. No weight changes were observed within the detectability of the instrumentation. More careful examination of the patent and other reports from Hooper led to the conclusion that Hooper may have misinterpreted thermal effects as his 'Motional Field' effects. There is a possibility that the claimed effects are below the detection thresholds of the instrumentation used for these tests. CASI Accession Number: N95-28893

I have two problems with the methodology used by the NASA scientists in the above experiment.
First -- The amount of ampere-turns used in the NASA experiment was substantially lower than the amount used by Hooper. Hooper found that his effect increased in proportion the square of the current. If you were motivated to verify that the Hooper effect exists, would you not try to conduct the experiment with MORE current, rather than less? Second -- NASA conducted it's tests by energizing the coils and making measurements in an immediate on-off mode, rather than letting things run for a while as Hooper did. NASA's reason for doing this was to avoid errors due to thermal effects. This makes sense. But what does not make sense is that if you are trying to verify an original experiment and you make changes, you have an obligation to also conduct the experiment in it's original mode. To do otherwise is bad science. But what could be wrong with testing things in an immediate on-off mode? Well, it can be seen in other experiments that a gravitational effect sometimes results from macroscopic spin alignment of the quantum angular momentum of a large number of microscopic particles. It has been demonstrated in other experiments that it takes time for these particles to come into alignment. For example in the inventions of Henry Wallace it sometimes took minutes for the "kinemassic" gravito- magnetic field to fully manifest itself. The reason that it takes time for particles to come into alignment, could be much the same reason that it takes

time to permanently magnetize a magnet. Wallace found that the "kinemassic" effect occurs with elemental materials which have a component of unpaired spin in the atomic nucleus. This includes all common isotopes of copper, which of course is the material used in Hooper's coils.

Incidently, NASA essentially has an economic monopoly in the lucrative market for microgravity materials research. -- Robert Stirniman

The Hooper effect can be readily demonstrated in the "Two Moving
Magnets Experiment". In this experiment, magnetic flux is provided by equal strength opposite pole magnets, moving uniformly in opposite directions. The induced motional electric field that is generated in a conductor, is found to be twice that which would result from a single magnet, while remarkably, the sum of the magnetic B field is zero. This experiment is easy to setup and verify in any electronics laboratory with a pair of magnets, a wire, and a voltmeter. In fact, you may wrap the conductor, in electrostatic or magnetic shielding, and find the same result.
-- Nils Rognerud

Oleg Jefimenko, "Causality, Electromagnetic Induction, and Gravitation", Electret Scientific, Star City, (1992)

Oleg Jefimenko, "Force Exerted on a Stationary Charge by a Moving Electric Current or a Moving Magnet", American Journal of Physics, Vol 61, pages 218-
222 (1993)

Apparently, there are some VERY interesting clues to the nature of the universe that are related to the phenomenon of SPIN. It might get very interesting if someone were to make a project of assembling in one place all the information that has been observed, alleged, suspected, or speculated about concerning unexpected effects related to spin, along with all the traditional Newtonian results, stir, add some seasoning, and see what comes out.
For example, in quantum mechanics, if you want to measure the spin axis of an electron, you do an experiment in which you ASSUME an axis, make a measurement of the correlation (the dot product) of that axis with the actual axis of spin for that electron, and theory says you can determine at least how close your guess was. It was a major surprise for the first expermienters with this to find that the guess was always right: whatever spin axis you assume turns out to be correct, exactly dead accurate. You must be a VERY good guesser. Out of this experimental result came the concept of "isospin". Which in itself is kind of weird in that objects with zero radius can still exhibit spinx. But I find the idea that the spin is wherever you guess it might be to be even weirder and to need a better model that predicts this result. -- John Sangster
----

Paper: gr-qc/9311036
From: jaegukim@cc.kangwon.ac.kr
Date: Tue, 30 Nov 93 13:47:52 +0900
Gravitational Field of a Moving Spinning Point Particle, by Jaegu Kim, 7 pages,
The gravitational and electromagnetic fields of a moving charged spinning point particle are obtained in the Lorentz covariant form by transforming the Kerr--Newman solution in Boyer--Lindquist coordinates to the one in the coordinate system which resembles the isotropic coordinates and then covariantizing it. It is shown that the general relativistic proper time at the location of the particle is the same as the special relativistic one and the gravitational and electromagnetic self forces vanish.

Jaegu Kim, "Gravitational Field of a Moving Point Particle", Journal of the Korean Physical Society, Vol 27 No 5, Oct 94, Pages 484-492

Jaegu Kim, "Gravitational Field of a Moving Spinning Point Particle", Journal of the Korean Physical Society, Vol 27 No 5, Oct 94, Pages 479-483

In the above papers, Dr. Kim derives solutions for the Einstein-Maxwell equations for: a charged massless point particle, a point particle having mass but no charge, a point particle having mass and charge, a massless point particle with charge and spin, and finally -- a point particle having charge, mass, and spin. He determines that there is a region of space around a charged spinning mass in which the gravitational force is negative.

The ability to generate a negative gravity effect may come as no surprise to experimenters who have worked with Bose-Einstein condensates, superfluids, or superconductor material in which the angular momentum of quantum level particles can become aligned along a "macroscopic" spin axis. And it is probably also not a surprise to those who have looked at devices such as the inventions of Henry Wallace, in which a macroscopic body is mechanically spun at high speed in order to cause a "kinemassic" gravito-magnetic field due to spin alignment of the nucleus of elemental materials having an odd number of nucleons (un-paired spin).

Paper: GR-QC/9504023
Date: Mon, 17 Apr 1995 10:43:50 +0900
Title: Pure spin-connection formulation of gravity and classification of energy-momentum tensors
Author: Mathias PILLIN Report-no: YITP/U-95-
12
It is shown how the different irreducibility classes of the energy-momentum tensor allow for a pure spin-connection formulation. Ambiguities in this formulation especially concerning the need for constraints are clarified.

From: R.Bursill@sheffield.ac.uk (R Bursill)
Subject: Hi Tc SC and gravitational shielding
Date: Fri, 6 Oct 1995 03:14:41 GMT

Is anyone familiar with the experiments in Tampere Finland, by Podkletnov et al on weak gravitational shielding from a Meissner levitating, rotating disk of high-Tc superconducting material? The paper is: E. Podkletnov and R. Nieminen, Physica C 203 (1992) 441. E. Podkletnov and A. D. Levit have another paper now, a Tampere University of Technology report, January 1995 (Finland), the experiment having being repeated (I assume no one believed it the first time?).
In the 1st experiment a 5 g sample of silicon dioxide was found to loose around 0.05 % of its weight when placed at a distance of 15 mm from the SC disk. The SC disk had diameter 145 mm and thickness 6 mm. Under rotation of the disk the effect increased up to 0.3 %. In the 2nd experiment samples of different composition and weight (10-50 g) were placed at distances of 25 mm to 1.5 m from the disk. The mass loss went as high as around 2 %. I found out about this through a theoretical preprint by Giovanni Modanese, a Von Humboldt Fellow from the Max Plank institute. The preprint no. is MPI-PhT/95-44, May 1995. A colleage got it from hep-th@babbage.sissa.it, paper 9505094. Modanese thinks that it is something to do with the bose condensate from the SC interacting with the gravitational field. He uses some non-perturbative quantum theory on the Regge lattice to attempt to understand the effect. Must be a little bit like explaining cold fusion with the standard tools - couldn't be done. We all know what happened to cold fusion but at the time a professor from my department said in a public lecture that the product of the believability and the potential importance if true was of order 1.
- Robert Bursill

E. Podkletnov and R. Nieminen, "A Possibility of Gravitational Force Shielding by Bulk YBa2Cu3O7-x Superconductor", Physica C 203 (1992) pp 441-444.

E. Podkletnov and A.D. Levi, "Gravitational Shielding Properties of Composite Bulk YBa2Cu3O7-x Superconductor Below 70 C Under Electro-Magnetic Field", Tampere University of Technology report MSU-95 chem, January 1995.

HEP-TH/9505094
Theoretical analysis of a reported weak gravitational shielding effect Author: G. Modanese (Max-Planck-Institut, Munich) Report-no: MPI-PhT/95-44 May 1995
Under special conditions (Meissner-effect levitation and rapid rotation) a disk of high-Tc superconducting material has recently been found to produce a weak shielding of the gravitational field. We show that this phenomenon has no explanation in the standard gravity theories, except possibly in the non-
perturbative quantum theory on the Regge lattice. More data, and independent repetitions of the experiment are however necessary.

ABSTRACT SUPR-CON/9601001
From: Modanese Giovanni Date: Wed, 17 Jan 1996 21:54:45 +0100 (MET) Updating the analysis of Tampere's weak gravitational shielding experiment Author: Giovanni Modanese
Report-no: UTF-367/96
The most recent data about the weak gravitational shielding produced in Tampere by Podkletnov and coworkers through a levitating and rotating HTC superconducting disk show a very weak dependence of the shielding value ($\sim 1 \%$) on the height above the disk. We show that whilst this behaviour is incompatible with an intuitive vectorial picture of the shielding, it is consistently explained by our theoretical model. The expulsive force observed at the border of the shielded zone is due to energy conservation.

NASA is conducting experiments similar to the anti-gravity shielding experiments done in Tampere Finland. A scientist named Ning Li at the University of Alabama Huntsville, is reported to be consulting with NASA. She has written some interesting articles about the relationship between superconductors and gravtiation. Here are references to some of her published articles, and a few related items:

AUTHOR(s): Li, Ning and Torr, D.G.
TITLE(s): Effects of a Gravitomagnetic Field on pure superconductors
In: Phys. Rev. D,
JAN 15 1993 v 43 n 2 Page 457

AUTHOR(s): Torr, Douglas G. Li, Ning
TITLE(s): Gravitoelectric-Electric Coupling via Superconductivity.
In: Foundations of physics letters.
AUG 01 1993 v 6 n 4 Page 371

AUTHOR(s): Li, Ning and Torr, D.G.
TITLE(s): Gravitational effects on the magnetic attenuation of superconductors.
In: Physical review. b, condensed matter. SEP 01 1992 v 46 n 9 Page 5489

AUTHOR(s): Peng, Huei
TITLE(s): A New Approach to Studying Local Gravitomagnetic Effects on a Superconductor.
In: General relativity and gravitation.
JUN 01 1990 v 22 n 6 Page 609

AUTHOR(s): Mashhoon, Bahram Paik, Jung Ho Will, Clifford M.
TITLE(s): Detection of the gravitomagnetic field using an orbiting superconducting gravity gradiometer. Theoretical principles. In: Physical review. D, Particles and fields. MAY 15 1989 v 39 n 10 Page 2825

I haven't had the opportunity to read the articles by Drs. Li and Torr, but I am told that in one of her articles, Dr Li provides the following interesting comment --

" a detectable gravitomagnetic field, and in the presence of a time-dependent applied magnetic vector potential field, a detectable gravitoelectric field could be produced"

There is also some information about Dr Ning Li at: http://isl-garnet.uah.edu/RR93/uahmatsci.html

Dr Li is with the Applied Materials Lab at the University of Alabama at Huntsville. She works closely with Dr Douglas Torr. One of their primary interests is development and production of exotic materials in a microgravity environment -- a peculiar coincidence, or maybe not, with the writing of physical theories about how to produce anti-gravity in the laboratory.

Here's an unusual article from the website. ---------------

Can gravity be 'made' in the laboratory?

A theory that might lead to the creation of measurable manmade gravitational fields has been developed by physicists at UAH.

If the theoretical work is borne out in the laboratory, it will prove that physicist Albert Einstein was correct in predicting that moving matter generates two kinds of gravitational fields: gravito-magnetic and gravito-electric. The 'artificial' gravitational field would be generated inside a container made of a superconducting material, said Dr. Douglas Torr, a research professor of physics and director of UAH's Optical Aeronomy Laboratory. "I think we can at the very least generate a microscopic field ..." If Einstein was right, the amount of gravito-magnetic energy produced by an object is proportional to its mass and its movement, explained Dr. Ning Li, a research scientist in UAH's Center for Space Plasma and Aeronomic Research. To create the artificial gravitational fields, Torr and Li propose placing a superconducting container in a magnetic field to align ions that are spinning or rotating in tiny circles inside the superconducting material. Their theory predicts the existence of ionic spin or rotation in a superconductor in a magnetic field.

There are persistent rumors among UFO-buffs that NASA already has an operating microgravity chamber, located in Houston TX and/or Huntsville AL. One person, Robert Oechsler, reports that he has personally been inside NASA's antigrav chamber. But, that's another story. For more info, see the books "Alien Contact" and "Alien Update" by Timothy Good.

Paper: hep-th/9412243
From: Vu.Ho@sci.monash.edu.au
Date: Sat, 31 Dec 1994 17:06:38 +1100
Title: Gravity as a coupling of two electromagnetic fields Author: Vu B Ho
A discussion on a possibility to represent gravity as a coupling of two equal and opposite electrogmanetic fields. Classically the existence of equal and opposite electromagnetic fields can be ignored altogether. However, the problem can be viewed differently if we want to take into account possible quantum effects. We know that in quantum mechanics the potentials themselves may be significant and they may determine the dynamics of a particle in a region where the fields vanish. (Aharonov and Bohm 1959, Peshkin and Tonomura 1983)

AN EXPERIMENT TO TEST THE GRAVITATIONAL AHARONOV-BOHM EFFECT Ho, Vu B. Morgan, Michael J. Monash University, Clayton, Victoria, Australia 1994 8 PAGES, Australian Journal of Physics (ISSN 0004-9506) vol. 47, no. 3 1994 p. 245-252 HTN-95-92507 The gravitational Aharonov-Bohm (AB) effect is examined in the weak-field approximation to general relativity. In analogy with the electromagnetic AB effect, we find that a gravitoelectromagnetic 4-vector potential gives rise to interference effects. A matter wave interferometry experiment, based on a modification of the gravity-induced quantum interference experiment of Colella, Overhauser and Werner (COW), is proposed to explicitly test the gravitoelectric version of the AB effect in a uniform gravitational field. CASI Accession Number: A95-87327

I recommend you get a copy of Aharonov and Bohm's classic paper "Significance of Electromagnetic Potentials in the Quantum Theory" published in The Physical Review in 1959. One of the important things that Aharonov and Bohm did was to demonstrate that the electromagnetic potentials are richer in properties than the Maxwell fields. The field is

an artifical mathematical construct from which emerges the whole idea of a continuum. When you can wean yourself of this intellectual crutch you will be ready to do real physics. Both GR and QM are addicted to the same falsehood.
-- Charles Cagle

In the Aharonov-Bohm effect it has been determined theortically and experimentally that there is a measurable effect on a charged particle due to the electromagnetic vector potential. Which of course would be no surprise, except that the effect occurs even in areas of space where the value of the classical electromagnetic fields vanish. A quantum phase shift, detectable via particle interferometry, is found to occur due to the magnetic vector potential A. The effect on a charged particle occurs in regions which are completely shielded from classical electromagnetic fields.

A dual of the Aharonov-Bohm effect is the Aharonov-Casher effect, where it is shown that measurable effects of spin-precession of a particle's magnetic moment can occur due to the electric potential, even in areas of space where the classical electrical field is completely absent.

Prior to the revolutionary paper by Aharonov and Bohm in 1959, the importance of the electomagnetic potential and related interferometry effects, was suggested in articles by Edmund Whittaker in 1903 and 1904. And, what is now known as the Aharonov-Bohm effect, was explicitly identified in an earlier paper on electron optics by Ehrenberg and Siday in 1949.

E.T. Whittaker, "On the partial differential equations of mathematical physics," Mathematische Annalen, Vol 57, 1903, pages 333-355. In this paper Whittaker demonstrates that all scalar EM potentials have an internal, organized, bidirectional EM plane-wave structure. Thus there exists an electromagnetics that is totally internal to the scalar EM potential. Since vacuum/spacetime is scalar potential, then this internal EM is in fact "internal" to the local potentialized vacuum/ spacetime.
-- Tom Bearden

E.T. Whittaker, "On an expression of the electromagnetic field due to electrons by means of two scalar potential functions," Proceedings of the London Mathematical Society, Series 2, Vol 1, 1904, pages 367-372. In this paper Whittaker shows that all of classical electromagnetics can be replaced by scalar potential interferometry. This ignored paper anticipated the Aharonov-Bohm (AB) effect by 55 years, and drastically extended it as well. Indeed, it prescribes a macroscopic AB effect that is distance-independent, providing a direct and engineerable mechanism for action-at-a-distance. It also provides a testable hidden-variable theory that predicts drastically new and novel effects. -- Tom Bearden

W. Ehrenberg and R. W. Siday, Proc. Phys. Soc. London, B62, 8 (1949) Ten years earlier than Aharonov and Bohm, Ehrenberg and Siday formulated the science of electron optics by defining the electron refractive-index as a function of electromagnetic potential. Near the end of their paper, they discuss "a curious effect", which is exactly the AB effect. On the two sides of a magnetic flux, the vector potential has different values. This means a different refractive index for two geometrically equivalent paths. This difference in refractive index would cause an observable phase shift.
-- Jun Liu

Y. Aharonov and D. Bohm, "Significance of Electromagnetic Potentials in the Quantum Theory," Physical Review, Second Series, Vol 115 no 3, pages 485-491 (1959)
Effects of potentials on charged particles exist even in the region where all the fields (and therefore the forces on the particles) vanish, contrary to classical electrodynamics. The quantum effects are due to the phenomenon of interference. These effects occur in spite of Faraday shielding. The Lorentz force does not appear anywhere in the fundamental quantum

theory, but appears only as an approximation that holds in the classical limit. In QM, the fundamental physical entities are the potentials, while the fields are derived from them by differentiation.

Herman Erlichson, "Aharonov-Bohm Effect and Quantum Effects on Charged Particles in Field-Free Regions," American Journal of Physics, Vol 38 No 2, Pages 162-173 (1970).

M. Danos, "Bohm-Aharonov effect. The quantum mechanics of the electrical transformer," American Journal of Physics, Vol 50 No 1, pgs 64-66 (1982).

Bertram Schwarzschild, "Currents in normal-metal rings exhibit Aharonov-Bohm Effect," Physics Today, Vol 39 No 1, pages 17-20 (Jan 1986)

S. Olariu and I. Iovitzu Popescu, "The quantum effects of electromagnetic fluxes," Reviews of Modern Physics, Vol 57 No2, April 1985.

Yoseph Imry and Richard Webb, "Quantum Interference and the Aharonov- Bohm Effect", Scientific American, April 1989, pages 56-62

E. Merzbacher, "Single Valuedness of Wave Functions", American Journal of Physics, Vol 30 No 4, pages 237-247 (April 1962)

Yoseph Imry, "The Physics of Mesoscopic Systems", Directions in Condensed Matter Physics, World Scientific Publishing (1986)

Richard Webb and Sean Washburn, "Quantum Interference Fluctuations in Disordered Metals", Physics Today, Vol 41 No 12 pages 46-53, Dec 1989

"STAR WARS NOW! The Bohm-Aharonov Effect, Scalar Interferometry, and Soviet Weaponization" By T. E. Bearden, Tesla Book Company

Peshkin M. and Lipkin H.J. "Topology, Locality, and Aharonov-Bohm Effect with Neutrons" Physical review letters APR 10 1995 v 74 n 15

Yakir Aharonov and Ady Stern, "Origin of the geometric forces accompanying Berry's geometric potentials", Physical Review letters. DEC 21 1992 v 69 n 25 Page 3593

Yakir Aharonov, Jeeva Anandan, and Sandu Popescu, "Superpositions of time evolutions of a quantum system and a quantum time-translation machine." Physical review letters. JUN 18 1990 v 64 n 25 Page 2965

QUANTUM PHYSICS, ABSTRACT QUANT-PH/9506038 From: "Jun Liu" Date: Sun, 25 Jun 1995 03:25:05 -0400
Potential Effect: Aharonov-Bohm Effect of Simply Connected Region Author: Jun Liu
Comments: Prediction of a new effect. Numerical estimate given for experimental verification. The referees disagree with each other on the existence of this effect.
We study a generalization of Aharonov-Bohm effect, the potential effect. The discussion is focused on field-free effects in simply connected region, which obviously can not have any local field-flux. Among the published discussions about this kind of effects, it is generally agreed that this kind of effect does not exist due to gauge invariance. However, there are also opinions that this effect is a trivial variation of Aharonov-Bohm effect and therefore there is no need to check its existence. To my knowledge, it has neverbeen tested. My first goal here is to supply enough theoretical reason to motivate the experimental test of this effect. I start with an intuitive derivation, then I introduce a wave-front theory as a theoretical consideration. Logically, the existence of potential effect implies the existence of the AB effect, but not vice versa. The purpose of this paper is to provide a physical connection in the opposite direction.

QUANTUM PHYSICS, ABSTRACT QUANT-PH/9510004 From: "Jun Liu" Date: Thu, 5 Oct 1995 04:30:27 -0400

The Real Significance of the Electromagnetic Potentials Author(s): J`un L'iu
The importance of the potential is revealed in a newly discovered effect of the potential. This paper explore the same issue introduced in quant-
ph/9506038 from several different aspects including electron optics and relativity. Some people fail to recognize this effect due to a wrong application of gauge invariance.

In the above two papers, Dr Liu proposes a theory of the electromagnetic potential which is a radical extension of the well known Aharonov-Bohm effect. In the second paper he is barely able to contain his frustration about repeated publication rejections over the last four years from leading physics journals. He provides a theoretical foundation for his potential theory, as well as some relatively straight forward suggestions for experiments which might confirm the theory. But there is an enormous problem. Liu's theory violates the concept of invariance of physical parameters under an electromagnetic gauge transformation. Electromagnetic gauge invariance is a cornerstone in the foundation of quantum theory and QED, and it is also part and parcel linked with the dogma of light speed invariance. In other words, heresy.

The AB effect is invariant under an electromagnetic gauge transformation. While a phase-shift occurs in the AB effect, it can be identified only over a closed path and is impossible to identify with any specific "local" region of space. Furthermore, in the AB effect, there is no interaction relating to a transfer of energy or momentum. Maintaining the idea of gauge invariance is a little harder to do in the Aharonov-Casher effect, but it can be accomplished by "gauging away" the physical effects of magnetic spin precession by using a combination of factors from the classical Maxwell fields along with the electromagnetic potential. It has the look of an elaborate parlor trick, but so does most of QED.

Liu's theory predicts that the electromagnetic potential acts like a kind of "refractive index" to wave propogation, and is similar in some respects to what was predicted in the earlier paper on electron optics by Ehrenberg and Siday in 1949. The result is that in some circumstances an electromagnetic potential causes a change in wavelength, and in other circumstances causes a change in phase (AB effect). An effect on wavelength would be manifested as a change in the envelope of the interference pattern, rather than merely a shift in the pattern. In Liu's theory an exchange of energy and momentum becomes possible. His theory is relatively easy to test and verify, but oddly or not, no one has yet done so. Maybe because we already "know" it can't be true?

One interesting prediction of Liu's theory is that electromagnetic potential will result in time dilation. He doesn't appear to be aware that there is already experimental evidence that this occurs. See references to inventions and experiments by people such as Saxl, Barker, and Keller, which demonstrate time dilation in an electric potential. Time dilation can be viewed equivalently as a shift in wavelength. Liu wishes for someone to conduct an experiment to test for a change in wavelength by using a quantum interferometer. A fine idea. But what about those experimenters who have already measured this effect with a clock? Also see a variety of references here to theories and experiments which relate the scalar electric potential to the gravitational field, and time dilation is a well know, and experimentally verified, prediction of general relativity.

The Aharonov-Bohm effect has sparked a revolution in physical thought. There are a variety of new ideas and experiments, such as verification of Liu's theory, which could soon begin to fan it to a flame. When the flame becomes sufficiently illuminating, watch the political scientists begin to scramble for a comfortable seat nearer the fire. -- Robert Stirniman
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Over the last five years, there have been over 300 papers published about various aspects of Aharonov-Bohm and Aharonov-Casher effects, and quantum interferometry. The subject relates to nearly all aspects of modern physics. Here are selected examples:

AUTHOR(s): Semon, Mark D.
TITLE(s): The Aharonov-Bohm Effect: Still a Thought-Provoking
Experiment.
In: Foundations of physics.
JUL 01 1988 v 18 n 7 Page 731

AUTHOR(s): Furuya, Kazuhito
TITLE(s): Transient Response of the Aharonov-Bohm Effect.
In: Japanese journal of applied physics. part 1,
FEB 01 1989 v 28 n 2 Page 303

AUTHOR(s): Chetouani, L. Guechi, L. Hammann, T.F.
TITLE(s): Exact path integral solution of the coulomb plus
Aharonov-Bohm potential.
In: Journal of mathematical physics.
MAR 01 1989 v 30 n 3 Page 655

AUTHOR(s): Lee, Patrick A.
TITLE(s): Gauge field, Aharonov-Bohm Flux, and high-Tc
superconductivity.
In: Physical review letters.
AUG 07 1989 v 63 n 6 Page 680

AUTHOR(s): Bezerra, V.B.
TITLE(s): Gravitational analogs of the Aharonov-Bohm effect.
In: Journal of mathematical physics.
DEC 01 1989 v 30 n 12 Page 2895

AUTHOR(s): Reznik, B. Aharonov, Y.
TITLE(s): Question of the nonlocality of the Aharonov-Casher effect.
In: Physical review. D, Particles and fields. DEC 15 1989 v 40 n 12 Page 4178

AUTHOR(s): Stovicek, P.
TITLE(s): The Green function for the two-solenoid Aharonov-Bohm
effect.
In: Physics letters: [part A]
NOV 27 1989 v 142 n 1 Page 5

AUTHOR(s): Ellis, J.R.
TITLE(s): Dirac magnetic monopole and the Aharonov-Bohm solenoid in
the Poincare gauge.
In: Journal of physics A: Mathematical and general. JAN 07 1990 v 23 n 1 Page 65

AUTHOR(s): Gerber, A. Deutscher, G.
TITLE(s): AC-to-DC conversion and Aharonov-Bohm effect in percolating
superconducting films.
In: Physical review letters.
MAR 26 1990 v 64 n 13 Page 1585

AUTHOR(s): Hagen, C.R.
TITLE(s): Exact equivalence of spin-1/2 Aharonov-Bohm and
Aharonov-Casher effects.
In: Physical review letters.
MAY 14 1990 v 64 n 20 Page 2347

AUTHOR(s): Afanase'ev, G.N.
TITLE(s): Old and new problems in the theory of the Aharonov-Bohm
effect.
In: Soviet journal of particles and nuclei. JAN 01 1990 v 21 n 1 Page 74

AUTHOR(s): Silverman, M.P.
TITLE(s): Two-solenoid Aharonov-Bohm experiment with correlated
particles.
In: Physics letters: [part A]
AUG 13 1990 v 148 n 3/4 Page 154

AUTHOR(s): Gornicki, Pawel
TITLE(s): Aharonov-Bohm Effect Vacuum Polarization.
In: Annals of physics.
SEP 01 1990 v 202 n 2 Page 271

AUTHOR(s): Gal'tsov, D.V. Voropaev, S.A.
TITLE(s): Bremsstrahlung polarization in the Aharonov-Bohm effect.
In: Moscow University physics bulletin.
1990 v 45 n 1 Page 8

AUTHOR(s): Padmanabhan, T.
TITLE(s): Vacuum polarization around an Aharonov-Bohm solenoid.

In: Pramana.
MAR 01 1991 v 36 n 3 Page 253

AUTHOR(s): Hagen, C.R.
TITLE(s): Spin dependence of the Aharonov-Bohm Effect.
In: International journal of modern physics A. JUL 30 1991 v 6 n 18 Page 3119

AUTHOR(s): Dupuis, Nicolas Montambaux, Gilles
TITLE(s): Aharonov-Bohm flux and statistics of energy levels in
metals.
In: Physical review B: Condensed matter. JUN 15 1991 v 43 n 18 Page 14390

AUTHOR(s): Ortiz, M.E.
TITLE(s): Gravitational anyons, Chern-Simons-Witten gravity and the
gravitational Aharonov-Bohm effect.
In: Nuclear physics. b.
SEP 30 1991 v 363 n 1 Page 185

AUTHOR(s): Bezerra, V.B.
TITLE(s): Gravitational Aharonov-Bohm effect in a locally flat
spacetime.
In: Classical and quantum gravity.
OCT 01 1991 v 8 n 10 Page 1939

AUTHOR(s): Sitenko, Y.A.
TITLE(s): The Aharonov-Bohm effect and the inducing of vacuum charge
by a singular magnetic string.
In: Nuclear physics. b.
MAR 23 1992 v 372 n 3 Page 622

AUTHOR(s): March-Russell, John Preskill, John Wilczek, Frank
TITLE(s): Internal frame dragging and a global analog of the
Aharonov-Bohm effect.
In: Physical review letters.
APR 27 1992 v 68 n 17 Page 2567

AUTHOR(s): Krive, I.V. Rozhavsky, A.S.
TITLE(s): Non-Traditional Aharonov-Bohm Effects in Condensed Matter.
In: International journal of modern physics. B. MAY 10 1992 v 6 n 9 Page 1255

AUTHOR(s): Krive, I. V. Zvyagin, A. A.
TITLE(s): Aharonov-casher effect in half-integer spin
antiferromagnets.
In: Modern physics letters. B, Condensed matter ph JUN 20 1992 v 6 n 14 Page 871

AUTHOR(s): Zubkov, M.A. Polikarpov, M.I.
TITLE(s): Aharonov-Bohm effect in lattice field theory.
In: JETP letters.
APR 25 1993 v 57 n 8 Page 461

AUTHOR(s): Duru, I. H.
TITLE(s): Casimir Force Between Two Aharonov-Bohm Solenoids.
In: Foundations of physics.
MAY 01 1993 v 23 n 5 Page 809

AUTHOR(s): Takai, Daisuke Ohta, Kuniichi
TITLE(s): Aharonov-Bohm effect in the presence of magnetic flux and
electrostatic potential.
In: Physical review. b, condensed matter. JUL 15 1993 v 48 n 3 Page 1537

AUTHOR(s): Allman, B.E. Cimmino, A. Klein, A.G.
TITLE(s): Observation of the scalar Aharonov-Bohm effect by neutron
interferometry.
In: Physical review. A.
SEP 01 1993 v 48 n 3 Page 1799

AUTHOR(s): Jensen, Bjorn Kucera, Jaromir
TITLE(s): On a gravitational Aharonov-Bohm effect.
In: Journal of mathematical physics.
NOV 01 1993 v 34 n 11 Page 4975

AUTHOR(s): Maeda, J. Shizuya, K.
TITLE(s): Aharonov-Bohm and Aharonov-Casher effects and
electromagnetic angular momentum.
In: Zeitschrift fur Physik C; particles and fields. 1993 v 60 n 2 Page 265

AUTHOR(s): Afanasiev, G.N.

TITLE(s): Toroidal solenoids in an electromagnetic field and toroidal Aharonov-Casher effect.
In: Physica scripta.
OCT 01 1993 v 48 n 4 Page 385

AUTHOR(s): Moreau, William Ross, Dennis K.
TITLE(s): Complementary electric Aharonov-Bohm effect.
In: Physical review. A, Atomic, molecular, and opt JUN 01 1994 v 49 n 6 Page 4348

AUTHOR(s): Ho, Vu B. Morgan, Michael J.
TITLE(s): An Experiment to Test the Gravitational Aharonov-Bohm
Effect.
In: Australian journal of physics.
1994 v 47 n 3 Page: 245

AUTHOR(s): Zeiske, K. Zinner, G. Helmcke, J.
TITLE(s): Atom interferometry in a static electric field: Measurement
of the Aharonov-Casher phase.
In: Applied physics. b, lasers and optics. FEB 01 1995 v 60 n 2/3 Page: 205

AUTHOR(s): Sazonov, S.N.
TITLE(s): On Aharonov-Bohm Effect in Multiconnected Superconductor.
In: Acta physica Polonica, A.
DEC 01 1994 v 86 n 6 Page 987

AUTHOR(s): Reznik, B.
TITLE(s): Gravitational analogue of the Aharonov-Casher effect.
In: Physical review d: particles, fields, gravitat MAR 15 1995 v 51 n 6 Page 3108

AUTHOR(s): Oh, Sangchul Ryu, Chang-Mo
TITLE(s): Persistent spin currents induced by the Aharonov-Casher
effect in mesoscopic rings.
In: Physical review B: Condensed matter. MAY 15 1995 v 51 n 19 Page 13441

AUTHOR(s): Leadbeater, M. Lambert, C.J.
TITLE(s): Mesoscopic Superconducting Analogs of the
Aharonov-Bohm-Casher Effect.
In: Physical review letters.
MAY 29 1995 v 74 n 22 Page 4519

AUTHOR(s): Cook, Richard J. Fearn, Heidi Milonni, Peter W.
TITLE(s): Fizeau's experiment and the Aharonov-Bohm effect.
In: American journal of physics.
AUG 01 1995 v 63 n 8 Page 705

AUTHOR(s): Yi, J. Jeon, G. S. Choi, M. Y.
TITLE(s): Dual Aharonov-Casher effect and persistent dipole current.
In: Physical review B: Condensed matter. SEP 15 1995 v 52 n 11 Page 7838

AUTHOR(s): Audretsch, Jurgen Jasper, Ulf Skarzhinsky, Vladimir D.
TITLE(s): Bremsstrahlung of relativistic electrons in the
Aharonov-Bohm potential.
In: Physical review d: particles, fields, gravitat FEB 15 1996 v 53 n 4 Page 2178

AUTHOR(s): Skarzhinsky, Vladimir D. Audretsch, Jurgen Jasper, Ulf
TITLE(s): Electron-positron pair production in the Aharonov-Bohm
potential.
In: Physical review d: particles, fields, gravitat FEB 15 1996 v 53 n 4 Page 2190

Time out for a summary.

. Hooper, as well as Carr, Rognerud, Jefimenko, et al, find that a electromagnetic effect which is not shieldable, and hence difficult to distinguish from gravitation, results from equal and opposite electric currents (dipole-current), and that a similar effect can also be generated by a moving magnet or a moving electric current.

. Recent experiments in Tampere Finland, discover a gravitational shielding effect from a levitated rotating superconductor disk. This is similar in some respects to Hooper's invention, with the equal-and-opposite electric current being generated in a superconductor disk via the Meissner effect.

. Sansbury, Volkov, Brown, Teller, Blackett, Zollner, et al, provide theoretical arguments as well as some experimental indications that equal-and-
opposite electric charge (dipole-charge) is similar, or equivalent, to a static gravitational field. And that alignment of electric dipoles in matter and in vacuum polarization, can result in a force which is not shieldable, and not easily distinguishable from gravity. Conversely, it is well know that a gravitational field, an acceleration, or a mechanical force, causes a dipole moment (polarization) to occur within a dielectric material.

. Wallace, Laithwaite, Barnett, et al, discover that gravitational and electromagnetic field effects occur due to alignment of the microscopic spin of quantum particles with the angular momentum spin axis of a larger macroscopic body.

. Aharonov and Bohm discover that an effect can occur on an electrically charged particle due to the magnetic vector potential, in regions of space where the classic Maxwell fields vanish. Originally -- on the outside of infinitely long solenoid coil (with the magnetic field cancelled by equal-and-
opposite currents). Others have conducted this experiment using a toroidal coil coated with superconductor material (generating an equal-and-opposite current) to cause the Maxwell magnetic field to vanish. A similar effect, Aharonov-Casher is disovered to occur due to the electric scalar potential, in regions of space where the Maxwell electric field vanishes.

. Whittaker, and Eherenberg and Siday, have written theories which are precursors to Aharonov-Bohm, suggesting that the electromagnetic potential is a far richer and more fundamental thing than the Maxwell fields. The classical Maxwell fields are regarded as artifical abstractions. We can also note that Maxwell's theory itself, was originally much richer in variables (20 equations and 20 unknowns), before it was simplified by Gibbs and Heaviside, to the vector formlation which we know as "Maxwell's" equations.

. Vu Ho authors a recent paper suggesting experiments relating the electromagnetic potential and the Aharonov-Bohm effect to gravitation. And in a more recent paper, using the mathematics of differential geometry and general relativity, Dr Ho demonstrates that gravity can be expressed mathematically as a coupling of two equal-and-opposite electromagnetic fields.

. Jun Liu authors recent papers suggesting that the electromagnetic potential is of paramount importance. Liu's theory predicts that "local" effects can result from the potential in regions where the Maxwell fields vanish -- a violation of the theory of invariance under electric gauge transformations. Liu theory predicts that time dilation will occur in an electric potential. Saxl, Barker, and Keller have conducted earlier experiments which demonstrate time dilation in an electric potential.

Ning Li, a consulting scientist to NASA's Marshall Space Center, who we might presume to know something, authors papers about the relationship of gravito-electric and and gravito-magnetic forces to the electromagnetic potential, and methods for generation of gravitational effects with superconductor material. According to Dr Li -- "a detectable gravitomagnetic field, and in the presence of a time-dependent applied magnetic vector potential field, a detectable gravitoelectric field could be produced."

How many clues do we need? Equal-and-opposite electric sources (dipole- charges and/or dipole-currents) appear to effect the electromagnetic potential in ways which are indistinguishable from gravitation. And you know what they say about things that look like a duck.

The net sum of equal and opposite electromagnetic vectors is a zero vector, but it is NOT the same situation as no vector. For skeptics and diehards who are still having a hard time accepting the idea of electrogravitics, here's a simple experiment. Stand on a train track between two locomotives which are pushing on you with equal force in opposite directions. You will exhibit no net motion. None the less, you may soon begin to notice that something important is happening. -- Robert Stirniman

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Jorge Pullin Wed, 1 Feb 1995 22:55:17 -0500 (EST)
Matters of Gravity, a newsletter for the gravity community Author: Jorge Pullin (PSU), editor.

Loops, knots, gauge theories and quantum gravity Rodolfo Gambini and Jorge Pullin ; foreword by Abhay Ashtekar. New York: Cambridge University Press, 1996. Cambridge monographs on mathematical physics ISBN 0-521-47332-2 (hc)

A number of reports which have been prepared for the USAF are publicly available, These reports can be obtained from the "Defense Technical Information Center" (DTIC). Cameron Station, Alexandria VA 22304, 800-225-3842

Cravens D.L., "Electric Propulsion Study", Prepared for the Astronautics Laboratory, Air Force Space Technology Center, at Edwards AFB. August 1990. AL-TR-89-040

Mead F.B. Jr, et al, Advanced Propulsion Concepts - Project Outgrowth, AFRPL-TR-72-31, (JUN 1972).

Mead F.B. Jr, "Exotic Concepts for Future Propulsion and Space Travel", In Advanced Propulsion Concepts, 1989 JPM Specialist Session, (JANNAF) Chemical Propulsion Information Agency, CPIA Publication 528, p.93-99, (May 24, 1989).

Talley R.L, "Twenty First Century Propulsion Concept", Veritay Technology Inc, East Amherst NY. Prepared for the Phillips Laboratory, Air Force Systems Command, Propulsion Directorate, Edwards AFB. May 1991. PL-TR-91-3009

Talley R.L., 21st Century Propulsion Concept, AFAL-TR-88-031, Apr 88.

Talley R.L., Final report on NYS contract no. (88)-166 of NYS Science and Technology Foundation with Veritay Technology, Inc., P.O. Box 305, East Amherst NY 14051.

Forward R.L., 21st Century Space Propulsion Study, AL-TR-90-030, Final Report on Contract FO4611-87-C-0029, Air Force Astronautics Lab (AFSC), (Oct 1990). --AND-- Forward,R.L., 21st Century Space Propulsion Study (Addendum), PL-TR-91-3022, Final (Addendum), OLAC Phillips Lab, formally known as Air Force Astronautics Lab (AFSC), (June 1991).

Electric Propulsion Study by Dennis L. Cravens:

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AUTHOR(s): Woyk, E.
TITLE(s): Gravitomagnetics in Stationary Media.
In: The Astrophysical journal.
SEP 20 1994 v 433 n 1 p 1 Page 357

AUTHOR(s): Shahid-Saless, Bahman
TITLE(s): Local gravitomagnetic perturbations of the lunar orbit.
In: Physical review. D, Particles and fields.
DEC 15 1992 v 46 n 12 Page 5404

AUTHOR(s): Blockley, C.A. Stedman, G.E.
TITLE(s): Gravitomagnetic effects along polar geodesics about a
slowly rotating spherical mass in the PPN formalism. In: Physics letters: [part A]
JUL 09 1990 v 147 n 4 Page 161

AUTHOR(s): Zhang, Xiao-He
TITLE(s): Interactions of magnetohydrodynamic waves with
gravitomagnetic fields, and their possible roles in black-hole magnetospheres.
In: Physical review. D, Particles and fields.
DEC 15 1989 v 40 n 12
Page: 3858

AUTHOR(s): Khanna, Ramon
Camenzind, Max
TITLE(s): The Gravitomagnetic Dynamo Effect in Accretion Disks of
Rotating Black Holes.

In: The Astrophysical journal.
NOV 10 1994 v 435 n 2 p 2

AUTHOR(s): Casotto, S. Ciufolini, I. Vespe, F.
TITLE(s): Earth satellites and gravitomagnetic field.
In: Il nuovo cimento delle societa italiana di fisic MAY 01 1990 v 105 n 5 Page 589

AUTHOR(s): Mashhoon, Bahram Paik, Jung Ho Will, Clifford M.
TITLE(s): Detection of the gravitomagnetic field using an orbiting superconducting gravity gradiometer. Theoretical principles. In: Physical review. D, Particles and fields. MAY 15 1989 v 39 n 10 Page 2825

AUTHOR(s): Nordtvedt, K.
TITLE(s): Gravitomagnetic interaction and laser ranging to Earth satellites.
In: Physical review letters.
DEC 05 1988 v 61 n 23 Page 2647

There is a reprint of an article that appeared in "Interavia, Volume XI - No. 5, 1956" a March 23, 1956 article titled "Towards Flight without Stress or Strain... or Weight" This article has a photograph of T.T.Brown holding one of his flying disks, and another photograph of the flying disk by itself. There is some info on the opperation of the electrokinetic apparatus.

The 1956 paper "The Gravitics Situation" (prepared by Gravity Rand Ltd., a division of Aviation Studies Ltd. This includes six appendices with papers by various authors including the text from T. Townsend Brown's 1929 gravitor patent.

Many documents on Gravitoelectrics/Electrogravitation refer back to the 1952 Project Winterhaven. That project is said to contain information on a Mach 3 Combat Disc. Also, have any records related to other Projects with Mr. T.T. Brown been produced. I have seen his Lab notes 1 - 3 - 4. I was looking for 2 - 5 & 6. Also, the Bahnson et al Brown lab notes during his research days at Bahnson Labs in North Carolina 1957-60 period or about. I have a poor chopped up Lab Video on the subject. I'm looking for the full video the 45 minute one. Mine is a mere 23 minutes.

I have yet to track down an original document entitled: "The Flying Saucer: The Application of the Biefeld-Brown Effect to the Solution of Space Navigation" by Mason Rose. This 50's document details how a flying saucer operates. I have a copy of a re-write and it is outstanding. And I'm also looking for a document as seen on SIGHTINGS TV entitled: "PROJECT SILVER BUG" the 1955 USAF Flying Saucer Tests. Also, seeking a copy of PROJECT WINTERHAVEN by Thomas Townsend Brown on a MACH-3 Combat Disc. The British had a stake in as well as the USAF. It to is from the 1950's.
-- James Hartman, CaluNET - Future Science Admin. ----------------------------
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The Biefeld-Brown (spelling is correct) effect is described generally as the anomalous tendency of high voltage flat capacitors to display movement towards (usually) the positive pole. Effects are most often seen at potentials above 50kv. Thomas Townsend Brown held a few patents on devices using it. It's very controversial and is part of the subject of "electrogravitics", as some say that the BB effect is actually polar gravity peeking out from behind a high electrical gradient within a dielectric. Claims are that the mass of the dielectric is a factor in the magnitude of the effect as well as the capacitance and the gradient intensity. Should be fairly easy for the home-workshop experimenter to get a look at, but the difficulty seems to be in isolating the effect from ionic wind and simple electrostatic propulsive effects. Skeptics claim that those forces are all it ever was, but a few reports indicate that they may be wrong.

-- Rick Monteverde, Honolulu HI

The experiments involved freely suspended electrically charged capacitors, which were determined to possess angular momentum yet did not rotate. Source: Albert Einstein: Philosopher- Scientist, P. Schilpp, editor, 3rd ed., 1988, pp 522-523.

Schilpp, Paul Arthur, 1897- ed.
Albert Einstein: philosopher-scientist. [3d ed.] La Salle, Ill., Open Court [1970] xviii, 781 p. illus., facsim., ports. 25 cm. LC CALL NUMBER: QC16.E5 S3 1970

>From Richard Feynman's Lectures on Physics we learn that there is intrinsic field energy and momentum density associated with a static electro-
magnetic field configuration. When there is a change in the magnetic field, this field energy and momentum can be directly converted into kinetic energy and mechanical momentum. Feynman illustrates this with an electromagnetic carousel paradox. In this paradox, a dielectric disk (which is embedded with small charged spheres along its circumference) rotates without any apparent "counter" torque in the system. Before this rotation occurs, the dielectric disk is immersed in a static magnetic field. The subsequent rotation occurs as a consequence to reducing the previously static magnetic field to zero. The angular momentum and rotational kinetic energy comes directly from the initial static magnetic field.
"The Feynman Lectures on Physics" by Richard Feynman, R.B. Leighton, and M. Sands, Volume II p 17-6

A Report on the T. Townsend Brown Conference: "Focus on Unconventional Energies: A Symposium on Electrical Propulsion & the Technology of Electro-Gravity"
April 15-16, 1994 Philadelphia Community College, Philadelphia, PA

This conference was held in tribute to Thomas Townsend Brown and I feel that it was a great success. About 15 speakers and 80 attendees provided a brief overview of Zero Point Energy theories, Free Energy devices, electrostatics theory, and antigravity experiments and documentation. Attendees came from as far away as California and Washington. The conference program advertised the following topics: "A Review of Advanced Energy Devices: Evidence, Promises, and Dangers" by Patrick Bailey (VP INE); "Thomas Townsend Brown's Electro-Gravities Research in the 1950's" by Tom Valone (Integrity Institute); "The Role of Electro-Statics" by Charles Yost (Electric Spacecraft Journal); "Thomas Townsend Brown's Research: A Challenge to Modern Science" by Elizabeth Rauscher (Tecnic Research Laboratories); "Electro-Gravitic Theory: Explaining the Operating Principle of Brown's Electric Disks" by Paul LaViolette (The Starburst Foundation); "A Panel Discussion on Biefeld-Brown and Beyond;" "Vortices in the Zero Point Energy" by Moray King; "Design of a Compact Marx Generator Triggered by a Blumlein Capacitor" by George Hathaway; "Thomas Townsend Brown's Final Gravito-Electric Research" by Josh Reynolds (New Wave Partners); "Townsend Brown Effects Reviewed" by Ron Kovac; "Pushing the Boundaries: Electro-Hydro Dynamic Potentials ..." by Henry Monteith, and "Gravity Drop Tests" by Don Kelly (SEA). - Patrick Bailey

I have the audio tapes from the T.T. Brown conference, 11 tapes in all, and I got a lot of good information from it. - Bob Reim (reim@advantor.com)

There is a connection between Townsend Brown and UFOs. Brown was the founder of NICAP (National Investigations Committee on Aerial Phenomena) Project Skylight, and Brown served as Vice Chairman pro tempore during during NICAP's organizational period in 1956.

Partial biography of Thomas Townsend Brown: 1922-23, private research laboratory, Pasadena, California; 1924-25, special electronics research, Denison University, Department of Physics; 1926-30, private research laboratory (astrophysics), Zanesville, Ohio, in collaboration with Dr. Paul Biefeld, Swazey Observatory, Granville, Ohio; 1930-33, Naval Research Laboratory (radiation and spectroscopy), Washington, DC; ... 1938, Assistant Engineering Officer (Lt. jg USNR) shakedown cruise USS NASHVILLE to Europe; 1939-40, Materials and Processes Engineer (aircraft), Glenn L. Martin Company, Baltimore; 1940-41, Officer-in-charge (Lt. USNR), Magnetic and Acoustic Minesweeping, Research and Development, Bureau of Ships, Navy Department, Washington, D. C.; 1942-43, Officer-in-charge (Lt. Comdr. USNR), Atlantic Fleet Radar Materiel School and Gyro- compass School, Naval Operating Base, Norfolk, Virginia; 1944-45, Radar Consultant, Advanced Design Section, Lockheed Aircraft Corporation, Burbank, California; ...

Also, there was a T.T. Brown on the Condon committee for UFO studies. And some of Brown's above described Navy duties are coincident with some of the times and places in stories about the Montauk Project/ Philadelphia Experiment.

Quotation from a letter to William Moore from T. Townsend Brown dated 12/17/76 --

"I am still working on petroelectricity and the project is housed largely at Stanford Research Institute with additional assistance being provided by the University of California - Berkeley and the Ames Research center of NASA. Unfortunately, under the circumstances, while this project is being evaluated for funding by ERDA we should not and cannot publish details..."

"Your next question concerns the airfoils. As far as I am aware, no rf is radiated. There is, of course, a static d.c. field which accompanies the airfoils in flight." -------------------------------

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It is very interesting to note that Townsend Brown was the pioneer in this field, and was not able to obtain very much support for his work until the 1950's. During that time, there was much discussion of gravity and antigravity within the aerospace industry and in the magazine "Aviation Week." Then the Gravity Research Group (GRG) published a detailed summary report of their review of research into "Electrostatic Motion, Dynamic Counterbary, and Barycentric Control" (i.e. "Antigravity"). This report is the last public report that any researchers have been able to find for us that deals with the physical effects of electrostatics, electrodynamics, and gravity control. (It is also worth noting that this report was found in the Wright Patterson Air Force Base Library "TL 565 A9" and was not listed in the library catalog). So, after the mid-1950's to the present, no other information regarding the technology of electrodynamics and its effect on gravity has been able to be found in any of the un-classified U.S. literature.

- Patrick Bailey

I have the FIVE (5) lab books of TT Brown's R&D at the Bahnson Co. in Salem, N. Carolina 1958-9. I also have some other letters and drawings of the lab plus the only surviving 16mm colour film of the various stages of his work at Bahnson Labs.

I was in contact with Dr Brown in 1983 by phone and by mail. He died of lung cancer not long after in Oct of 1985. He told me that a lot of people including Bill Morre had attributed more to his work than he had really done. In particular, he was only marginally connected with the Philadelphia Experiment as such. His main theme of R&D was dielectrics and the Biefeld-

Brown effect. He was not an electromagnetics man... only electrostatics.

>From 1983 to 1991 or so I was in frequent communication with J. Frank King who was TT Brown's boss at the Bahnson Co. J. Frank was a good man and a good friend of mine. He, too, died in Dec 1989. Before he died I was given rights to reproduce and share letters, files, drawings, patent submissions, films etc

from his personal files on TT Brown, George Adamski, Dr Ilka, T Henry Moray and others.
J Frank warned me a long time ago to take what TT Brown said with a 'grain of salt' because Townsend had a habit of 'stretching the truth' a bit to get funding which he was always in need of.... So, I warn you now in good faith: If you seek lost or hidden technology in Brown's lab notes, I don't think you will find it there; however, I am prepared to make photocopies available to you.
There are about 750 pages in all. I would need to charge you AUS$50 per notebook which would include the air mail charges as well. In US$ that would be about US$38 per notebook. The film is available as are the notebooks (I think) from The Electric Spacecraft Journal in the US (Charles Yost on 704-
252-8083, FAX 202-683-3511. -- Stan Deyo

As far as I know, the last thing Brown published before his death was, "On The Possibilities of Optical-Frequency Gravitational Radiation", 2/14/1976 and 8/30/1976. I don't know where it was originally published. But you can get copy from:

Rex Research, P.O. Box 19250, Jean NV 89019

It is part of NR 046-BT2/B17-BRV "T. Brown: Petro-Voltaics" (Gravito-Electric Conversion). Most people think Brown was just into flying capacitors he was into much much more... -- Bob Paddock
----

Here are some titles by Townsend Brown:

"The Wizard of Electro-Gravity: The Man Who Discovered how UFOs are powered." by William L. Moore. In UFO Report magazine. Unfortunately the issue date is not on this copy, and the magazine is at work. A lot of the same information can be found in the book "The Philadelphia Experiment: Project Invisibility" by William L. Moore with Charles Berlitz. Chapter 10 "The Force Fields of Townsend Brown". These two items are the same, I just don't know which one came first. Also there is more than one book with the title "The Philadelphia Experiment". You want the one with ISBN 0-449-20526-6. "The Townsend Brown Electro-Gravity Device: A Comprehensive Evaluation by the Office of NAVAL Research" 15 September 1952. Such as "How I Control Gravity by T. Townsend Brown" from Science and Invention Magazine Aug. 1929. "Townsend Brown and his Anti-Gravity Discs" by Gaston Burridge in Fate Magazine. No issue date is visible. "Electrical Self-Potential in Rocks" by T.Townsend Brown, some time after 1/1976, but again no source is visible. "Another Step Toward Anti-Gravity" by Gaston Burridge in The American Mercury, June 1958, p77.
"Towards Flight without Stress or Strain... or Weight" by Intel, Washington, D.C. [Doesn't make since but that is what it says.] Some one just on the list here just reinvented "The Fluid Pump" by T.Townsend Brown for the Whitehall-Rand Group, Washington DC -------
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Paper: gr-qc/9207002
From:
RCAPOVI%CINVESMX.BITNET@ricevm1.rice.edu Date: Tue, 21 Jul 1992 17:52 CST
Title: Remarks on Pure Spin Connection Formulations of Gravity Authors: Riccardo Capovilla and Ted Jacobson Abstract: In the derivation of a pure spin connection action functional for gravity two methods have been proposed. The first starts from a first order lagrangian formulation, the second from a hamiltonian formulation. In this note we show that they lead to identical results for the specific cases of pure gravity with or without a cosmological constant.

Paper: hep-th/9210110 (Phys. Rev. D47, R5214 (1993).) From: pullin@mail.physics.utah.edu (Jorge Pullin) Date: Tue, 20 Oct 92 11:18:14 MDT
QUANTUM EINSTEIN-MAXWELL FIELDS: A UNIFIED VIEWPOINT FROM THE LOOP REPRESENTATION, R. Gambini, J. Pullin, 13pp. no figures. We propose a naive unification of

Electromagnetism and General Relativity based on enlarging the gauge group of Ashtekar's new variables. We construct the connection and loop representations and analyze the space of states. In the loop representation, the wavefunctions depend on two loops, each of them carrying information about both gravitation and electromagnetism. We find that the Chern-Simons form and the Jones Polynomial play a role in the model.

Paper: gr-qc/9301012
From:
porrati@MAFALDA.PHYSICS.NYU.EDU
(Massimo Porrati) Date: Wed, 13 Jan 93 20:17:21 -0500
Massive Spin-5/2 Fields Coupled to Gravity: Tree-Level Unitarity vs. the Equivalence Principle, Massimo Porrati, 6 pages. I show that the gravitational scattering amplitudes of a spin-5/2 field with mass $m\ll M_{Pl}$ violate tree-level unitarity at energies $\sqrt{s}\approx\sqrt{mM_{Pl}}$ if the coupling to gravity is minimal. Unitarity up to energies $\sqrt{s}\approx M_{Pl}$ is restored by adding a suitable non-minimal term, which gives rise to interactions violating the (strong) equivalence principle. These interactions are only relevant at distances $d\lequiv 1/m$.

Paper: gr-qc/9303014
From: ISTVAN@RMK520.RMKI.KFKI.HU
Date: Wed, 10 Mar 1993 16:24:01 +0100 (WET) MAXWELL FIELDS IN SPACETIMES ADMITTING NON-NULL KILLING VECTORS, by Istvan Racz, 7 pages,PACS numbers: 04.20.Cv, 04.20.Me, 04.40.+c We consider source-free electromagnetic fields in spacetimes possessing a non-
null Killing vector field, ξ^a. We assume further that the electromagnetic field tensor, F_{ab}, is invariant under the action of the isometry group induced by ξ^a. It is proved that whenever the two potentials associated with the electromagnetic field are functionally independent the entire content of Maxwell's equations is equivalent to the relation $\n^aT_{ab}=0$. Since this relation is implied by Einstein's equation we argue that it is enough to solve merely Einstein's equation for these electrovac spacetimes because the relevant equations of motion will be satisfied automatically. It is also shown that for the exceptional case of functionally related potentials $\n^aT_{ab}=0$ implies along with one of the relevant equations of motion that the complementary equation concerning the electromagnetic field is satisfied.

Paper: gr-qc/9310007 (Physica Scripta 48, 649 (1993)) From: harald@nordita.dk (Harald H. Soleng) Date: Mon, 4 Oct 93 13:18:04 +0100
INVERSE SQUARE LAW OF GRAVITATION IN (2+1)-DIMENSIONAL SPACE-TIME AS A CONSEQUENCE OF CASIMIR ENERGY, H. H. Soleng, 10 pages, LaTeX, Report: UPR-
0540-T, To appear in Physica Scripta. The gravitational effect of vacuum polarization in space exterior to a particle in (2+1)-dimensional Einstein theory is investigated. In the weak field limit this gravitational field corresponds to an inverse square law of gravitational attraction, even though the gravitational mass of the quantum vacuum is negative. The paradox is resolved by considering a particle of finite extension and taking into account the vacuum polarization in its interior.

Paper: gr-qc/9310019
From: rri!bri@rri.ernet.in (B.R.Iyer)
Date: Tue, 12 Oct 93 12:44:52 IST
THE FRENET SERRET DESCRIPTION OF GYROSCOPIC PRECESSION B.R.Iyer and C.V.Vishveshwara , 37 pages, Paper in Latex. The phenomenon of gyroscopic precession is studied within the framework of Frenet-Serret formalism adapted to quasi-Killing trajectories. Its relation to the congruence vorticity is highlighted with particular reference to the irrotational congruence admitted by the stationary, axisymmetric spacetime. General precession formulae are obtained for circular orbits with arbitrary constant angular speeds. By successive reduction, different types of precessions are derived for the Kerr - Schwarzschild - Minkowski spacetime family. The phenomenon is studied in the case of other interesting spacetimes, such as the De Sitter

and Godel universes as well as the general stationary, cylindrical, vacuum spacetimes.

Paper: gr-qc/9310030
From: khatsymovsky Date: Thu, 21 Oct 93 16:39:25 +0100
Can wormholes exist? V.Khatsymovsky, 10 pages, Plain LaTeX, preprint UUITP-20/1993
Renormalized vacuum expectation values of electromagnetic stress-energy tensor are calculated in the background spherically-symmetrical metric of the wormhole's topology. Covariant geodesic point separation method of regularization is used. Violation of the weak energy condition at the throat of wormhole takes place for geometry sufficiently close to that of infinitely long wormhole of constant radius irrespectively of the detailed form of metric. This is an argument in favour of possibility of existence of selfconsistent wormhole in empty space maintained by vacuum field fluctuations in the wormhole's background.

Paper: hep-th/9402046
From: LANDI@SUHEP.PHY.SYR.EDU
Date: Tue, 08 Feb 1994 15:09:39 -0500 (EST)
GRAVITY AND ELECTROMAGNETISM IN NONCOMMUTATIVE GEOMETRY, Giovanni Landi, Nguyen Ai Viet, Kameshwar C.Wali, 1 + 11 pages, Report # SU-4240-566,
We present a unified description of gravity and electromagnetism in the framework of a Z2 noncommutative differential calculus. It can be considered as a ``discrete version'' of Kaluza-Klein theory, where the fifth continuous dimension is replaced by two discrete points. We derive an action which coincides with the dimensionally reduced one of the ordinary Kaluza-Klein theory.

Paper: gr-qc/9404016
From: David Garfinkle Date: Sun, 10 Apr 1994 17:44:50 -0400
Generating new magnetic universe solutions from old. By David Garfinkle and M.A. Melvin. 17 pages
In this paper we apply the techniques which have been developed over the last few decades for generating nontrivially new solutions of the Einstein-Maxwell equations from seed solutions for simple spacetimes. The simple seed spacetime which we choose is the "magnetic universe" to which we apply the Ehlers transformation. Three interesting non-singular metrics are generated. Two of these may be described as "rotating magnetic universes" and the third as an "evolving magnetic universe." Each is causally complete - in that all timelike and lightlike geodesics do not end in a finite time or affine parameter. We also give the electromagnetic field in each case. For the two rotating stationary cases we give the projection with respect to a stationary observer of the electromagnetic field into electric and magnetic components.

Paper: gr-qc/9404065 (Phys. Rev. D50 (1994) 6190) From: carroll@marie.mit.edu (Sean Carroll) Date: Sun, 1 May 1994 16:35:00 -0400
Energy-Momentum Restrictions on the Creation of Gott Time Machines, by Sean M. Carroll, Edward Farhi, Alan H. Guth, and Ken D. Olum. Plain TeX, 41 pages incl. 9 figures. MIT-CTP #2252.
The discovery by Gott of a remarkably simple spacetime with closed timelike curves (CTC's) provides a tool for investigating how the creation of time machines is prevented in classical general relativity. The Gott spacetime contains two infinitely long, parallel cosmic strings, which can equivalently be viewed as point masses in (2+1)-dimensional gravity. We examine the possibility of building such a time machine in an open universe. Specifically, we consider initial data specified on an edgeless, noncompact, spacelike hypersurface, for which the total momentum is timelike (i.e., not the momentum of a Gott spacetime). In contrast to the case of a closed universe (in which Gott pairs, although not CTC's, can be produced from the decay of stationary particles), we find that there is never enough energy for a Gott-like time machine to evolve from the specified data; it is impossible to accelerate two particles to sufficiently high velocity. Thus, the no-CTC theorems of Tipler and Hawking are enforced in an open (2+1)-dimensional universe by a mechanism different from that which operates in a closed universe. In proving our result, we

develop a simple method to understand the inequalities that restrict the result of combining momenta in (2+1)-dimensional gravity.

Paper: gr-qc/9405050
From: MATSAS@IFT.UESP.ANSP.BR
Date: Mon, 23 May 1994 15:01 BSC (-0300 C)
DO INERTIAL ELECTRIC CHARGES RADIATE WITH RESPECT TO UNIFORMLY ACCELERATED OBSERVERS?, George E.A. Matsas, 6 pages (REVTEX 3.0), IFT-P017/94. We revisit the long standing problem of analyzing an inertial electric charge from the point of view of uniformly accelerated observers in the context of semi-classical gravity. We choose a suitable set of accelerated observers with respect to which there is no photon emission coming from the inertial charge. We discuss this result against previous claims [F. Rohrlich, Ann. Phys. (N.Y.) vol: 22, 169 (1963)]. (This Essay was awarded a Honorable Mention for 1994 by the Gravity Research Foundation.)

Paper: gr-qc/9406032
From: wam@tdo-serv.lanl.gov (Warner A. Miller) Date: Mon, 20 Jun 94 14:44:42 MDT
Spin Dynamics of the LAGEOS Satellite in Support of a Measurement of the Earth's Gravitomagnetism, Salman Habib, Daniel E. Holz, Arkady Kheyfets, Richard A. Matzner, Warner A. Miller and Brian W. Tolman, 16 pages, RevTeX, LA-UR-94-1289. (Part I of II, postscript figures in Part II). LAGEOS is an accurately-tracked, dense spherical satellite covered with 426 retroreflectors. The tracking accuracy is such as to yield a medium term (years to decades) inertial reference frame determined via relatively inexpensive observations. This frame is used as an adjunct to the more difficult and data intensive VLBI absolute frame measurements. There is a substantial secular precession of the satellite's line of nodes consistent with the classical, Newtonian precession due to the non-sphericity of the earth. Ciufolini has suggested the launch of an identical satellite (LAGEOS-3) into an orbit supplementary to that of LAGEOS-1: LAGEOS-3 would then experience an equal and opposite classical precession to that of LAGEOS-1. Besides providing a more accurate real-time measurement of the earth's length of day and polar wobble, this paired-satellite experiment would provide the first direct measurement of the general relativistic frame-dragging effect. Of the five dominant error sources in this experiment, the largest one involves surface forces on the satellite, and their consequent impact on the orbital nodal precession. The surface forces are a function of the spin dynamics of the satellite. Consequently, we undertake here a theoretical effort to model the spin ndynamics of LAGEOS. In this paper we present our preliminary results.

Paper: gr-qc/9407003
From: William Bruckman Date: Tue, 5 Jul 94 09:06:49 EDT
Generation of Electro and Magneto Static Solutions of the Scalar-Tensor Theories of Gravity, William Bruckman, 28 pages, LaTeX. The field equations of the scalar-tensor theories of gravitation are presented in different representations, related to each other by conformal transformations of the metric. One of the representations resembles the Jordan-Brans-Dicke theory, and is the starting point for the generation of exact electrostatic and magnetostatic exterior solutions. The corresponding solutions for each specific theory can be obtained by transforming back to the original canonical representation, and the conversions are given for the theories of Jordan-Brans-Dicke, Barker, Schwinger, and conformally invariant coupling. The electrostatic solutions represent the exterior metrics and fields of configurations where the gravitational and electric equipotential surfaces have the same symmetry. A particular family of electrostatic solutions is developed, which includes as special case the spherically symmetric solutions of the scalar-tensor theories. As expected, they reduce to the well-known Reissner-Nordstrom metric when the scalar field is set equal to a constant. The analysis of the Jordan-Brans-Dicke metric yields an upper bound for the mass-radius ratio of static stars, for a class of interior structures.

Paper: gr-qc/9407030

From: Marco SISSA +39(40)3787522 Date: Thu, 21 Jul 1994 15:10:04 +0200
QUANTUM ELECTROMAGNETIC WORMHOLES AND GEOMETRICAL DESCRIPTION OF THE ELECTRIC CHARGE by Marco Cavaglia 13 pages, PLAIN TEX, Report No: SISSA 92/94/A (to appear in Phys. Rev. D15).
I present and discuss a class of solutions of the Wheeler-de Witt equation describing wormholes generated by coupling of gravity to the electromagnetic field for Kantowski-Sachs and Bianchi I spacetimes. Since the electric charge can be viewed as electric lines of force trapped in a finite region of spacetime, these solutions can be interpreted as the quantum corresponding of the Ein-stein--Rosen--Misner--Wheeler electromagnetic geon.

Paper: gr-qc/9409060 (Annals of Physics vol. 240 432--458 (1995)) From: soleng@surya11.cern.ch (Harald SOLENG) Date: Thu, 29 Sep 94 14:01:03 +0100
Modification of the Coulomb potential from a Kaluza-Klein model with a Gauss-
Bonnet term in the action, by H. H. Soleng and O. Gron, 27 pages, compressed and uuencoded postscript file with unpacking instructions; major revision to section IV.D.2 on pages 15-16 ("Corrections to the Coulomb potential at short distances") and to the figure on page 27, to be published in The Annals of Physics (NY), NORDITA 94/50 In four dimensions a Gauss-Bonnet term in the action corresponds to a total derivative, and it does not contribute to the classical equations of motion. For higher-dimensional geometries this term has the interesting property (shared with other dimensionally continued Euler densities) that when the action is varied with respect to the metric, it gives rise to a symmetric, covariantly conserved tensor of rank two which is a function of the metric and its first and second order derivatives. Here we review the unification of General Relativity and electromagnetism in the classical five-dimensional, restricted (with g55 = 1) Kaluza-Klein model. Then we discuss the modifications of the Einstein-Maxwell theory that results from adding the Gauss-Bonnet term in the action. The resulting four-dimensional theory describes a non-linear U(1) gauge theory non-minimally coupled to gravity. For a point charge at rest, we find a perturbative solution for large distances which gives a mass-dependent correction to the Coulomb potential. Near the source we find a power-law solution which seems to cure the short-distance divergency of the Coulomb potential. Possible ways to obtain an experimental upper limit to the coupling of the hypothetical Gauss-Bonnet term are also considered.

Paper: hep-th/9410046
From: M.J. Duff Date: Fri, 7 Oct 94 13:04:15 BST
KALUZA-KLEIN THEORY IN PERSPECTIVE, M. J. Duff, 38 pages latex, NI-94-015 The Kaluza-Klein idea of extra spacetime dimensions continues to pervade current attempts to unify the fundamental forces, but in ways somewhat different from that originally envisaged. We present a modern perspective on the role of internal dimensions in physics, focussing in particular on superstring theory. A novel result is the interpretation of Kaluza-Klein string states as extreme black holes.(Talk delivered at the Oskar Klein Centenary Nobel Symposium, Stockholm, September 19-21, 1994.)

Paper: gr-qc/9509018
From: nunez@venus.fisica.unlp.edu.ar (NUNEZ Carlos) Date: Fri, 8 Sep 95 15:05:13 EST
Title: On Pseudospherically Symmetric Repulsive Gravitational Field Authors: Luis A. Anchordoqui, Graciela S. Birman, Jose D. Edelstein and Carlos Nunez Report-no: La Plata-Th 95/23 The solution of Einstein vacuum equation, for a static pseudospherically symmetric system, is presented. It describes a singular solution that produces a repulsive gravitational field with an event horizon. We analyse particle motion in such a gravitational field and comment on some interesting features of the solution. -------
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"The Origin of the Electromagnetic Interaction in Einstien's Unified Field Theory", Antoci,S. General Relativity and Gravitation, Vol 23 No 1, 1991
Recently it has been shown that, if sources are appended in a certain way to the field equations of Einstein's unified theory, the contracted Bianchi identities and the field operations appear endowed with definite physical meaning. The theory looks like a gravoelectrodynamics in a polarizable Riemmannian continuum. The wealth of the implied possibilities is far richer than in the so-called Einstein-Maxwell theory. ------------------------------

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Paper: HEP-TH/9411092
From: hssong@phyy.snu.ac.kr
Date: Mon, 14 Nov 94 15:19:29 KST
Title: Factorization and polarization in linearized gravity Authors: S.Y. Choi, J.S. Shim, H.S. Song Comments: 45 pages, figures are included (uses pictex), RevTex Report-no: KEK-TH-415, HYUPT-94/10, SNUTP 94-03, We investigate all the four-body graviton interaction processes: gX -> gamma X, gX -> gX, and gg -> gg,
with X as an elementary particle of spin less than two in the context of linearized gravity except the spin-3/2 case. We show explicitly that gravitational gauge invariance and Lorentz invariance cause every four-body graviton scattering amplitude to be factorized. We explore the implications of this factorization property by investigating polarization effects through the covariant density matrix formalism in each four-body graviton scattering process.

Causality, electromagnetic induction, and gravitation : a different approach to the theory of electromagnetic and gravitational fields/ Oleg D. Jefimenko. Star City [West Virginia] : Electret Scientific Co., c1992. xii, 180 p. : LC CALL NUMBER: QC665.E4 J44 1992
SUBJECTS: Electromagnetic fields. Gravitational fields. Causality. Maxwell Equations.

COUNTER-GRAVITATION: The sustaining of an object in space by means of a counter-gravitational effect produced through the action of an electric field upon the object. Associated with the effects of levitation in this manner, is a simultaneous appearance of a strange luminous halo that appears at about 500,000 volts.

Sources: American Philosophical Society, Proceedings. Philadelphia, PA, years 1914-1929. Articles on Charles F. Brush's experiments.

Electrical Experimenter. "Can Electricity Destroy Gravitation?", New York, March 1918.

Electrical Experimenter. "Piggott's Electro-gravitation Experiment", Vol. 8, 1920.

Hooper, William J., New Horizons in Electric, Magnetic, and Gravitational Field Theory, Principia College, Elsah, IL, 1974.

The Scientific Papers of James Clerk Maxwell. Vol. II, W.D. Niven (ed.), Constable & Co., London, 1965. "Le Sage Theory of Gravitation".

Transactions of the Academy of Science. "Nipher's Gravitation Experiments", Vol. 23, pp. 163-192+, St. Louis, 1916.

US patent No. 1,006,786, Piggott.
3,518,462, Brown.
3,610,971, Hooper.

"Journal of Propulsion and Power" of the AIAA, R.H. Woodward Waesche, Science Applications International Corporation, Editor in Chief. This Journal is devoted to the advancement of the science and technology of aerospace propulsion and power through the dissemination of original archival papers contributing to advancements in airbreathing, electric, and advanced propulsion; solid and liquid rockets; fuels and propellants; power generation and conversion for aerospace vehicles; and the application of aerospace science and technology to terrestrial energy devices and systems. It is intended to provide readers of the Journal, with primary interests in propulsion and power, access to papers spanning the range from research through development to applications. Papers in these disciplines and the sciences of combustion, fluid mechanics, and solid mechanics as directly related to propulsion and power are solicited.

Published Bimonthly
AIAA Members $42.00 per year ($72.00 outside North America) Institutions $300.00 per year ($360.00 outside North America) -----------------------------

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I have recently come into possession of a paper on magneto-gravitics and field resonance systems, presented by A.C. Holt from NASA Johnson Space Center to the American Institute of Aeronautics and Astronautics' 16th Joint Propulsion Conference, June 30-July 2, 1980. Holt presents a project using an already existing system known as the Coherent Field and Energy Resonance System (CoFERS) [probably located at Los Alamos Labs' High Magnetic Field Research Laboratory]. CoFERS utilizes a toroidal-shaped energy guide with megagauss magnetic field sources located along radius vectors equally spaced around the toroid. CoFERS is shaped like a thick flying disc. Holt goes on to say: "By converying an object's normal space-time energy pattern to an energy pattern which differs substantially from the normal pattern, the gravitational forces acting on the object are changed. The object's new pattern interacts with the surrounding space-time and virtual energy patterns, such that the interactive forces are substantially altered. The alteration of the characteristics of the continuous field of force results in the apparent motion of the object *through space-time*." [...] "Since the gravitational forces acting on the propulsion system can be quickly altered to achieve the desired motion, the *spacecraft* can make right-angle turns at very-high velocities without adversely affecting the crew or system elements. The effective gravitational field the *spacecraft/ aircraft* experiences can be nearly simultaneously reoriented at a 90-degree angle, resulting in a smooth continuous motion as far as the occupants are concerned." [...] "The gravimagnetic system is perhaps best suited for use in and around ... a large mass such as the Earth." "While the gravimagnetic system is likely to be the first field-dependent propulsion system developed, the field resonance system will **bring stellar and galactic travel out of the realm of science fiction**. The field resonance system artificially generates an energy pattern which precisely matches or resonates with a virtual pattern associated with a distent space-time point. According to the model, if a fundamental or precise resonance is established, (using hydromagnetic wave fine-tuning techniques), the spacecraft will be very strongly and equally repelled by surrounding virtual patterns. At the same time, through the virtual many-dimensional structure of space-time, a very strong attraction with the virtual pattern of a distant space-time point will exist. ...this combination of very strong forces will result in the translocation of the spacecraft from its initial position through the many-dimensional virtual structure to the distant space-time point. [...] "A space-time 'jump' already appears to be supported by astrophysical research."

Should you wish the entirety of this report, "Prospects for a Breakthrough in Field Dependent Propulsion" by A.C. Holt, you can order it from AeroPlus Dispatch, 1722 Gilbreth Road, Burlingame, CA 94010; phone: (800)-662-AERO. The paper/conference number is AIAA-80-1233 (American Institute of Aeronautics and Astronautics, June 30-July 2, 1980 - 16th Annual Conference. -- Rich Boylan

There is also a great article discussing the work of A.C. Holt in the Electric Spacecraft Journal: Issue No. 5, June 30, 1992. -----------------------------

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GENERAL RELATIVITY & QUANTUM COSMOLOGY, ABSTRACT GR-

QC/9601024 From: MONTANARI@axpfe1.fe.infn.it
Date: Wed, 17 Jan 1996 13:01:16 +0100 (CET) Coherent Interaction of a Monochromatic Gravitational Wave with both Matter and Electromagnetic Circuits
Author(s): Enrico Montanari (1) , Pierluigi Fortini (1) ((1) University of Ferrara,INFN sezione di Ferrara, Italy) The interaction of a gravitational wave with a system made of an RLC circuit forming one end of a mechanical harmonic oscillator is investigated. We show that, in some configurations, the coherent interaction of the wave with both the mechanical oscillator and the RLC circuit gives rise to a mechanical quality factor increase of the electromagnetic signal. When this system is used as an amplifier of gravitational periodic signals a sensitivity of $10^{-
30}$ on the amplitude of the metric could be achieved.

GENERAL RELATIVITY & QUANTUM COSMOLOGY, ABSTRACT GR-QC/9602004 From: wells@cfaitamp2.harvard.edu (Jack Wells)
Date: Thu, 1 Feb 1996 16:50:06 -0500
Gravitational Interaction of Spinning Bodies, Center-of-Mass Coordinate and Radiation of Compact Binary Systems
Author(s): I.B. Khriplovich, A.A. Pomeransky Spin-orbit and spin-spin effects in the gravitational interaction are treated in a close analogy with the fine and hyperfine interactions in atoms. The proper definition of the cener-of-mass coordinate is discussed. The technique developed is applied then to the gravitational radiation of compact binary stars. Our result for the spin-orbit correction differs from that obtained by other authors. New effects possible for the motion of a spinning particle in a gravitational field are pointed out. The corresponding corrections, nonlinear in spin, are in principle of the same order of magnitude as the ordinary spin-
spin interaction.

HIGH ENERGY PHYSICS - THEORY, ABSTRACT HEP-TH/9601119 From: gonzalez@fyma.ucl.ac.be
Date: Tue, 23 Jan 1996 10:03:41 +0100 (MET) Spinning Relativistic Particle in an External Electromagnetic Field Author(s): M. Chaichian , R. Gonzalez Felipe , D. Louis Martinez The Hamiltonian formulation of the motion of a spinning relativistic particle in an external electromagnetic field is considered. The approach is based on the introduction of new coordinates and their conjugated momenta to describe the spin degrees of freedom together with an appropriate set of constraints in the Dirac formulation. For particles with gyromagnetic ratio $g=2$, the equations of motion do not predict any deviation from the standard Lorentz force, while for $g \neq 2$ an additional force, which corresponds to the magnetic dipole force, is obtained.

HIGH ENERGY PHYSICS - PHENOMENOLOGY, ABSTRACT HEP-PH/9601280 From: MAREK@taunivm.tau.ac.il
Date: 16 Jan 96 19:19 IST
The Strange Spin of the Nucleon
Authors: John Ellis (CERN) , Marek Karliner (Tel-Aviv Univ.) Comments: Invited Lectures at the International School of Nucleon Spin Structure, Erice, August 1995.
The recent series of experiments on polarized lepton-nucleon scattering have provided a strange new twist in the story of the nucleon, some of whose aspects are reviewed in these lectures. In the first lecture, we review some issues arising in the analysis of the data on polarized structure functions, focusing in particular on the importance and treatment of high-order QCD perturbation theory. In the second lecture some possible interpretations of the ``EMC spin effect'' are reviewed, principally in the chiral soliton (Skyrmion) approach, but also interpretations related to the axial $U(1)$ anomaly. This lecture also discusses other indications from recent LEAR data for an $\bar{s} s$ component in the nucleon wave function, and discusses test of a model for this component. Finally, the third lecture reviews the implications of polarized structure functions measurements for experiments to search for cold dark matter particles, such as the lightest supersymmetric particle and the axion, after reviewing briefly

the astrophysical and cosmological evidence for cold dark matter. ---------------------------------

----------------------------------- "Mechanical Propulsion From Unsymmetrical Magnetic Induction Fields" by: R.L. Schlicher A.W. Biggs W.J. Tedeschi 31st AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, July 10-12 1995

A method is presented for generating mechanical spacecraft propulsion from unsymmetrical magnetic induction fields. It is based on an unsymmetrical three-dimensional loop antenna structure driven by a repetitively-pulsed high-
current power supply. Antenna geometry is optimized for generating propulsive thrust rather than radiating electromagnetic energy. A magnetic field density gradient imbalances the magneto-mechanical forces that result from the interations of the internal magnetic induction field with the current in the conductors of the antenna structure.

From Richard Feynman's Lectures on Physics we learn that there is intrinsic field energy and momentum density associated with a static electro-magnetic field configuration. When there is a change in the magnetic field, this field energy and momentum can be directly converted into kinetic energy and mechanical momentum. Feynman illustrates this with an electromagnetic carousel paradox. In this paradox, a dielectric disk (which is embedded with small charged spheres along its circumference) rotates without any apparent "counter" torque in the system. Before this rotation occurs, the dielectric disk is immersed in a static magnetic field. The subsequent rotation occurs as a consequence to reducing the previously static magnetic field to zero. The angular momentum and rotational kinetic energy comes directly from the initial static magnetic field.

"The Feynman Lectures on Physics" by Richard Feynman, R.B. Leighton, and M. Sands, Volume II p 17-6

"Nonlinear Electromagnetic Propulsion System and Method", R.L. Schlicher Nineteenth Power Modulation Symposium of the IEEE, 1990 Page 139

"Classical Electrodynamics" by C.D. Jackson, 2nd Edition, John Wiley and Sons, New York, 1975

"The Feynman Lectures on Physics" Richard Feynman, R.B. Leighton, and M. Sands, Volume II p 27-9

US Patent #5142861, "Nonlinear Electromagnetic Propulsion System", R.L. Schlicher et al. 1992

Dr Peter Graneau has conducted experiments which he claims provide a demonstration of departure from classical electrodynamics at high currents levels. A force is found to exist in a direction longitudinal to current flow. Graneau ran a variety of types of experiments with a metal rod conductor immersed in a conductive fluid (mercury, or saline solution). With high amperage passing through the solution the metal rod is found to move in a longitudinal direction. There is no known explanation in conventional EM theory. This force may be similar to the force (v X B) that William Hooper finds in a noninductive coil. Or Graneau's longitudinal force may be a coupling between the electromagnetic and inertial/gravitational fields, which is predicted by some 5-D unified EM/gravitational theories -- predicted to result from a divergence of the electric current vector field. Graneau's experiments should be relatively easy to duplicate. I can find no record that anyone has ever done so. Graneau has also discovered apparently anomalous forces and effects in high energy electromechanical devices such as rail guns and induction motors.

AUTHOR: Graneau, Peter.
TITLE: Ampere-Neumann electrodynamics of metals/Peter Graneau.
PUBL.: Nonantuma, MA. : Hadronic Press,
FORMAT: ix, 311 p. : ill. ; 23 cm.
DATE: 1985
SUBJECT Metals--Electric properties--History.

Free electron theory of metals--History.
Electrodynamics--History.
Electric conductors--History.
ISBN: 0911767371

AUTHOR: Graneau, Peter
TITLE: Electromagnetic Jet Propulsion in the Direction
of Current Flow
In: Nature
June 18, 1982 No 295 Page 311

AUTHOR(s): Graneau, P.
TITLE(s): Ampere force calculation for filament fusion experiments.
In: Physics letters. a
MAR 22 1993 v 174 n 5/6 Page 421

AUTHOR(s): Graneau, P.
TITLE(s): Comment on "The motionally induced back-EMF in railguns".
In: Physics letters: [part A]
DEC 02 1991 v 160 n 5 Page 490

AUTHOR(s): Graneau, Peter
TITLE(s): The Difference between Newtonian and Relativistic Forces.
In: Foundations of physics letters.
OCT 01 1993 v 6 n 5 Page 491

AUTHOR(s): Graneau, P.
TITLE(s): Electrodynamic momentum measurements.
In: Journal of physics d: applied physics. DEC 01 1988 v 21 n 12 Page 1826

AUTHOR(s): Graneau, P.
TITLE(s): Far-action versus contact action.
In: Speculations in science and technology. 1990 v 13 n 3 Page 191

AUTHOR(s): Graneau, Peter
TITLE(s): Inertia's Riddle.
Summary: Inertia has been misunderstood ever since the time of
Galileo says Dr. Graneau.
In: Electronics world + wireless world.
JAN 01 1990 v 96 n 1647 Page 60

AUTHOR(s): Graneau, P.
TITLE(s): Longitudinal forces in Ampere's wire-arc experiment.
In: Physics letters: [part A]
MAY 08 1989 v 137 n 3 Page 87

AUTHOR(s): Graneau, P. Thompson, D.S. Morrill, S.L.
TITLE(s): The motionally induced back-emf in railguns.
In: Physics letters: [part A]
APR 30 1990 v 145 n 8/9 Page 396

AUTHOR(s): Graneau, Peter
TITLE(s): Nonlocal Action in the Induction Motor.
In: Foundations of physics letters.
OCT 01 1991 v 4 n 5 Page 499

AUTHOR(s): Graneau, P. Graneau, N.
TITLE(s): The role of Ampere forces in nuclear fusion.
In: Physics letters: [part A]
MAY 04 1992 v 165 n 1 Page 1

AUTHOR: Graneau, Peter.
TITLE: Underground power transmission : the science, technology,
and economics of high voltage cables / Peter Graneau. PUBL.: New York : Wiley,
FORMAT: x, 515 p. : ill. ; 24 cm.
DATE: 1979
SUBJECT: Electric cables
Electric power transmission
Electric lines--Underground
ISBN: 0471057576

I see that Graneau has devoted himself to the electric railgun. I looked a bit into this phenomena in 1994. I will now be able look a bit further. It seems that Graneau beleives in free energy in vacuum. The railgun and the theories about it are very controversial. There is a conflict between PhD Witalis, who works for the Swedish Defense, and the established plasmaphysiscists here in Uppsala. Witalis has condemned controlled hot fusion.
-- David Jonsson

MAGNETORESISTANCE IN METALS, by Pippard, A.B. Pippard provides the first systematic account of magnetoresistance in metals, the study of which has provided solid-state physicists with valuable information about electron motion in metals. The electrical resistance of a metal is usually changed when a magnetic field is applied to it, and at low temperatures the change may be very large indeed. Every metal behaves differently, and the effect has been widely used to elucidate details of electron motion in individual metals. Because there has been no systematic account of the phenomena, apart from review articles addressing special points, this book fills an obvious gap. Making no great demand on mathematical ability, it should be a valuable reference work for readers with a basic knowledge of undergraduate solid-state physics. The text is copiously illustrated with real experimental results. Cambridge Studies in Low Temperature Physics 2 1989 6 x 9 272 pp. 3 halftones 113 line diagrams Hardback 0-521-32660-5 $84.95 (J50.00)

Albert C. Crehore published "New Electrodynamics" in 1950. In this book he described how the motion of protons in the nucleus would produce gravitational field effects. Gravitational field effects such as counter-bary are used in the mainstream effort to develop non-areodynamic non-rocket flight systems that usually referred to as "anti-gravitational". By making use of the Crehore Paradigm it is possible to derive a method of producing counter-bary. It's most likely Crehore had no knowledge of Brown's 1928 British patent for a gravitator device that would have been a macroscopic analog of a Crehore atom.

Crehore, Albert C. (Albert Cushing), b. 1868. The mystery of matter and energy; recent progress as to the structure of matter, by Albert C. Crehore ... New York, D. van Nostrand company, 1917 LC CALL NUMBER: QC173 .C8
SUBJECTS: Matter--Constitution.

Crehore, Albert C. (Albert Cushing), b. 1868. The atom, by Albert C. Crehore ... New York, D. Van Nostrand company, 1920. xvi, 161 p. diagrs. 19 cm.
LC CALL NUMBER: QC173 .C75

A man named Gerry Vassilator is an electrogravity experimenter. Last I know (in 1991) he runs an information service called
MUUDO Experimental Videos
Delmar Ave
Staten Island, NY 10312.
(718)-356-9373.

There are many books available about anti-gravity and other weird science subjects from:
International Tesla Society
330-A West Uintah Street - Suite 215
Colorado Springs CO 80905-1095

The Anti-Gravity Handbook (revised ed.)
Compiled by D. Hatcher Childress
Published by - Adventures Unlimited Press
303 Main St., Kempton, Illnois 60949 USA
ISBN: 0-932813-20-8
Pub date: 1993 (First edition was in 1985) -----

Anti-gravity and the world grid / edited by David Hatcher Childress. 1st ed. Stelle, IL : Adventures Unlimited Press, c1987. 267 p. : ill. ; 26 cm. LC CALL NUMBER: BF1999 .A6386 1987
SUBJECTS: Antigravity. Grids (Cartography). Occultism. Childress, David Hatcher, 1957-
ISBN: 0932813038 (pbk.) : $12.95

The Anti-gravity handbook / compiled by D. Hatcher Childress. 1st ed. Stelle, Ill. : Adventures Unlimited Press, c1985 (1986 printing) 195 p. LC CALL NUMBER: QC178 .A58 1985
SUBJECTS: Antigravity.
Childress, David Hatcher, 1957-

ISBN: 0932813011 (pbk.) : $12.95

Pages, Marcel J. J.
Le defi de l'antigravitation: techniques antiponderales, utilisation de l'energie de l'espace [par] M. J. J. Pages. Paris, Chiron [1974] 306 p. LC CALL NUMBER: QC178 .P23
SUBJECTS: Antigravity. Force and energy. ISBN: 2702703097

Nipher, Francis Eugene, 1847-
Electricity and magnetism. A mathematical treatise for advanced undergraduate students. By Francis E. Nipher ... 2d ed., rev., with additions.
St. Louis, Mo., J. L. Boland book and stationery co., 1895 i.e. 1898 xi, 430 p. diagrs. 20 cm. --
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"My library research shows that as early as 1917, a Professor Nipher had found that the weight of substances could be reduced (become negative) by the application of electrostatic charges. (Science, Sept. 21, 1917, page 173).
Dr. Charles Brush, in a series of reports in the PROCEEDINGS OF THE AMERICAN PHILOSOPHICAL SOCIETY around 1922 found, in some well-thought-out-experiments, that weight was not only proportional to mass, but was affected by the atomic structure of the substances. For example, he found that for a given unit of mass and shape, BISMUTH falls faster than zinc or aluminum, in complete contradiction to Newton's Law of Gravity which they are still teaching in colleges today!
So far, the literature hasn't given me an answer. Incidentally, Otis Carr's work involved counter-rotating charged discs that supposedly produced thrust when they reached a certain speed in relation the the earth's rotational speed and became activated by free energy from space. Maybe he did have something." -- James E. Cox
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When individual molecules are not permanently magnetized, it is possible in some cases to have a relative magnetic permeability u which is less than one. Such a material, like hydrogen or BISMUTH, is called diamagnetic. It tends to expel magnetic field, and is repelled from regions of stronger magnetic field. The names paramagnetic and diamagnetic are sometimes confused: paramagnetic is analogous to a dielectric in an electric field, while diamagnetic is quite the opposite.

It is not possible to give a simple argument of why diamagnetism can occur. it is strictly speaking a quantum effect. However, one can see that there might be diamagnetic tendencies if electric currents can flow within molecules. An increasing magnetic field always tends to induce currents to flow in such a way as to tend to prevent the increase in the field. This is (at least temporarily) a diamagnetic kind of effect.

Thus the case where the relative magnetic permeablility $u < 1$, is connected with the flow of electric charges in a magnetic field. There is no analogous case with electric fields since isolated magnetic poles do no, so far as is known exist. - "The New Physics" edited by Paul Davies -----------------------
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GE engineer Henry Wallace found unusual gravitational effects in spinning odd atomic nulceide metals. Odd atomic nucleide metals are those in which the sum of the protons are not equal to the number of neutrons, i.e. more neutrons. See US patents 3626605 and 3626606. -Ron Kita
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"Also indicated in the embodiment is the orientation of the flux within the mass circuit, the latter being constructed preferredly of BISMUTH."
- Henry Wallace, US patent # 3626605, Method and Apparatus for Generating a Secondary Gravitational Force Field ------------
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AUTHOR(s): Uyeda, C. Yamanaka, T. Miyako, Y.
TITLE(s): Magnetic rotation of diamagnetic oxide crystals and
the origin of diamagnetic anistropies.

In: Physica B. Condensed matter.
MAY 01 1995 v 211 n 1/4 Page: 342

A while back I had the need to take a peek at a copy of the periodic table of elements. So I grabbed my old, dusty college chemistry book that I could never quite bring myself to toss. It's called "Chemical Principles", published WAY back in 1970. While looking through the book, I was stunned when I came across a discussion of the possibilities of new elements. "What lies ahead for the synthesis of transuranium elements? Will there be more radioactive and extremely short-lived species such as 97 through 104? It now appears as if there is a chance of reaching a new zone of stability that might even include some none radioactive elements. Calculations with nuclear shell models have led to the expectation that element 114, with 114 protons and 184 neutrons (both magic numbers in the new shell theory) would be an island of stability in a sea of instability."
I noted that some information was taken from an article in the April 1969 (pages 57-67) issue of "Scientific American" by Dr. Glenn Seaborg. In this article, there are excellent graphics showing the expected half-lives of all the heavyweights. They predict a fission half-life for the most stable isotope of 114 of 10 to the 16th years, and a alpha-decay half-life of 1,000 years. They didn't go into the same level of detail for 115, but it looks like the stuff would clock out considerably sooner by way of beta decay. BTW, according to the article, the proper terminology to denote an undiscovered element in a periodic column is the prefix "eka". Therefore element 115 should be eka-BISMUTH. Lose this Un-un-pentium crap! -Tom Mahood
----

Lazar is not the only one to theorize that the 114/115 area is stable. Check out the August 31, 1991 issue of New Scientist -- that respected peer-reviewed periodical. Find Glenn Seaborg's article called "The search for the missing elements." Seaborg is a renowned scientist who won the Nobel Prize for Chemistry in 1951. He and his research group at the Lawrence Berkeley Laboratory have discovered 10 of the transuranium elements. His article is very technical and interesting, and in it he has two separate graphs that show islands of stability at the 114/115 area. There is a sea of instability around these "islands." ------
----

AUTHOR(s): Bhattacharyya, S. Ghoshal, A. Ghatak, K.P.
TITLE(s): On the field emission from bismuth in the presence of a
quantizing magnetic field.
In: Fizika; a journal of experimental and theoretic APR 01 1991 v 23 n 2 Page 159

AUTHOR(s): Byrne, A. P. Birkental, U. Hubel, H.
TITLE: High-Spin States in 205Bi.
In: Zeitschrift fur Physik. A, Atomic nuclei 1989 v 334 n 3 Page: 247

AUTHOR(s): Vezzoli, G.C. Chen, M.F. Craver, F.
TITLE(s): Magnetically-related
properties of bismuth containing high
Tc superconductors.
In: Journal of magnetism and magnetic materials. AUG 01 1990 v 88 n 3 Page 351

AUTHOR(s): Bannerjee, D. Bhattacharya, R.
TITLE(s): Magnetic Properties of Single Crystals of Bismuth Doped
with Lead and Tin.
In: Physica status solidi. b: basic research. JAN 01 1990 v 157 n 1 Page 443

AUTHOR(s): Zhilyaev, I. N.
TITLE(s): Observation of kinetic paramagnetic effect in bismuth in a
transverse magnetic field.
In: Soviet journal of low temperature physics. SEP 01 1988 v 14 n 9 Page 502

AUTHOR(s): Mondal, M. Banik, S.N. Ghatak, K.P.
TITLE(s): Effect of a quantizing magnetic field on the Einstein
relation in bismuth.
In: Canadian journal of physics.
JAN 01 1989 v 67 n 1 Page 72

AUTHOR(s): Zheng, Q. Zeng, Z. Lai, W.
TITLE(s): The influence of Al on the electronic structure and
magnetic properties of doped MnBi with huge enhancement of Kerr rotation.
In: Journal of magnetism and magnetic materials. FEB 01 1992 v 104/107 p 2 Page 1019

CONDENSED MATTER, ABSTRACT COND-MAT/9601068 From: arghya@mri.ernet.in ("Arghya Taraphder")
Date: Wed, 17 Jan 1996 14:30:54 +0500
The Exotic Barium Bismuthates
Authors: A. Taraphder, Rahul Pandit, H.R. Krishnamurthy, T.V. Ramakrishnan We review the remarkable properties, including superconductivity, charge-
density-wave ordering, and metal-insulator transitions, of lead- and potassium-doped barium bismuthate. We discuss some of the early theoretical studies of these systems. Our recent theoretical work, on the negative-$U\/$, extended-Hubbard model for these systems, is also described. Both the large- and intermediate-$U\/$ regimes of this model are examined, using mean-field and random-phase approximations, particularly with a view to fitting various experimental properties of these bismuthates. On the basis of our studies, we point out possibilities for exotic physics in these systems. We also emphasize the different consequences of electronic and phonon-mediated mechanisms for the negative $U.\/$ We show that, for an electronic mechanism, the \secin \,\,phases of these bismuthates must be unique, with their transport properties {\it dominated by charge $\pm 2e$ Cooperon bound states}. This can explain the observed difference between the optical and transport gaps. We propose other experimental tests for this novel mechanism of charge transport and comment on the effects of disorder. ------------
----

Huston, David L.
The nature and possible significance of the Batamote copper-bismuth-silver anomaly, Pima County, Arizona / by David L. Huston and Paul K. Theobald. Washington : U.S. G.P.O. ; Denver, CO : For sale by the Books and Open-File Reports Section, U.S. Geological Survey, 1990. v, 19 p. : ill., maps LC CALL NUMBER: QE75 .B9 no. 1907 (ALTERNATE CLASS QE390.2.C6)
SUBJECTS: Copper ores--
Arizona--Batamote Mountains Region. U.S. Geological Survey bulletin ; 1907

Beck, Sherwin M.
Measured electron conversion ratios for the 1064-keV gamma ray of bismuth-207, by Sherwin M. Beck. Washington, National Aeronautics and Space Administration; [for sale by the Clearinghouse for Federal Scientific and Technical Information, Springfield, Va.] 1970. 39 p. illus. 27 cm. LC CALL NUMBER: TL521 .A3525 no. 6057
SUBJECTS: Bismuth--Isotopes. Nuclear counters. NASA technical note, NASA TN D-6057

The following is an excerpt from a telephone interview between Stanton Friedman (F) and Dr. Robert Sarabacher (S). Sarabacher was a prominent, US government scientist who had a secret briefing with Canadian scientist Wilbert Smith in 1950 and told Smith that that facts in a recent popular book about a UFO crash at Aztec, New Mexico were "essentially true" and that UFO's were classified by the US government 2 points higher than the H bomb. Sarabacher died in July 1986. Before Sarabacher died, Stanton Friedman did a phone interview with him. In between Friedmann's attempts to dig more UFO info out of Sarabacher, there was a lot of small talk, and since Sarabacher was fairly old, he tended to ramble a bit. However, a most interesting statement was made by Sarabacher:

F: Were you guys talking about nuclear powered flight at that time?

S: Oh, we were possibly, yes, but I held, had certain ideas see, one of the problems today, we really don't know what gravity is. We don't know and I had an idea, I'm willing to work on it in one of my theses but then my professor didn't believe me, but I had determined that BISMUTH did not obey the laws of gravity. So I thought that, "Gee, there's a leak". I might be able to get nature to tell me something.

So where exactly is Bismuth on the Periodic Table of Elements? Why directly above where 115 would fall if it exists. And the way the table works, (generally speaking) elements in the same column have similar properties. So, just what the hell was Sarabacher referring to? I don't know, but it's sure intriguing! It appears it was back when he was a grad student, in maybe the 30s or 40s. Whatever it was, it was at the very edge of the ability of equipment at the time. Does Bismuth possess any very subtle anomolous physical properties? -- Tom Mahood

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In the Wallace patent, #3626606, Figs. 7A and 7B are side views of a gravity-NEUTRALIZING FLYING SAUCER, or, if anchored to the ground, a ZERO-GRAVITY CHAMBER. Each oval diagram shows a motor spinning a central disc at a very high speed, about 28,000 RPM, and also rotating two other discs sandwiched around the first disc, via gears, at a much slower speed, perhaps 2,800 RPM, in the opposite direction. The two outer discs have extensions [counter-balanced via off-center axis] that, as they rotate, alternately make contact with two wide extensions from opposite walls of the spacecraft. The central disc should have shallow spiral-shaped grooves on both sides for air-bearings, to allow the needed very close contact with the two outer discs. Each of the two outer discs has ONLY ONE [counter-balanced] extension, each one pointed opposite (180 degrees) the extension of the other disc. The most important factor making it work is that the discs, extensions, and outer walls of the spacecraft MUST be made of any material(s) in which a very large majority of the atoms are of isotopes having "HALF-INTEGRAL ATOMIC SPINS", such as copper (3/2).
- Robert E. McElwaine

AUTHOR(s): Sun, W. Stephen, J.T. Wu, Y.
TITLE(s): Rotation-Induced Resonance and Second-Order Quadrupolar
Effects on Spin Locking of Half-Integer Quadrupolar Nuclei.
In: Journal of magnetic resonance. series a. OCT 01 1995 v 116 n 2 Page: 181

AUTHOR(s): Seliger, J. Blinc, R.
TITLE(s): Orientation dependences of quadrupolar spin-lattice
relaxation rates of spin-3/2 nuclei subject to a random two-site exchange in a high magnetic field: a theoretical study.
In: Journal of physics. Condensed matter : an Inst DEC 13 1993 v 5 n 50 Page: 9401

Thanks for the patent info about Wallace, I got them a few days ago and found it quite enjoyable. Actually, many people have had this notion at one time or another, I think Oleg Jefimenko wrote a book relating to this subject.
-- Keith Nagel

AUTHOR: Jefimenko, Oleg D.
TITLE: Electricity and magnetism : an introduction to the theory of
electric and magnetic fields / Oleg D. Jefimenko. EDITION: 2nd ed.
PUBL.: Star City, W. Va. : Electret Scientific Co.,
DATE: 1989
SUBJECT: Electromagnetism
ISBN: 0917406081

AUTHOR: Jefimenko, Oleg D.
TITLE: Electrostatic motors; their history, types, and principles of
operation (by) Oleg D. Jefimenko. With many illus., of which 57 are by David K. Walker.

PUBL.: Star City (W. Va.) Electret Scientific Co.
DATE: 1973
SUBJECT: Electrostatic apparatus and appliances

AUTHOR: Jefimenko, Oleg D.
TITLE: Causality, electromagnetic induction, and gravitation: a
different approach to the theory of electromagnetic and gravitational fields" b
PUBL: Star City [West Virginia] : Electret Scientific Co.,
DATE: 1992.
SUBJECTS: Electromagnetic fields. Gravitational fields. Causality. Maxwell Equations.

AUTHOR(s): Jefimenko, Oleg D.
TITLE(s): Direct calculation of electric and magnetic forces from
In: American journal of physics.
JUL 01 1990 v 58 n 7 Page 625

AUTHOR(s): Jefimenko, Oleg D.
TITLE(s): Direct calculation of the electric magnetic fields of an
electric point charge moving with constant velocity. In: American journal of physics.
JAN 01 1994 v 62 n 1 Page 79

AUTHOR(s): Jefimenko, Oleg D.
TITLE(s): Force exerted on a stationary charge by a moving electric
current or by a moving magnet.
In: American journal of physics.
MAR 01 1993 v 61 n 3 Page 218

AUTHOR(s): Jefimenko, Oleg D.
TITLE(s): Retardation and relativity: The case of a moving line
charge.
In: American journal of physics.
MAY 01 1995 v 63 n 5 Page 454

AUTHOR(s): Jefimenko, Oleg D.
TITLE(s): Retardation and relativity; Derivation of Lorentz-Einstein
transformation from retarded integrals for electric and magnetic fields.
In: American journal of physics.
MAR 01 1995 v 63 n 3 Page 267

AUTHOR(s): Jefimenko, Oleg D.
TITLE(s): Solutions of Maxwell's equations for electric and magnetic
fields in arbitrary media.
In: American journal of physics.
OCT 01 1992 v 60 n 10 Page 899

"Anti-Gravity Electronics", H. Aspden, Electroncis & Wireless World, Jan 1 1989, Vol 95 No 1635
Reinterpretation of Netwon's third law of motion suggests that it depends upon an electronic action. Electronic interaction therefore explains the paradoxical anti-gravity properties of the force precessed gyroscope.

"The Anti-Gravity Puzzle", Mark Ander, Professional Pilot, Aug 1 1989 Exploring the possibility of exceptions to Newton's inverse-square law of gravity, scientists pursue evidence in strange locations.

"The Latest Antigravity Gossip", Rock & Ice, Nov 1 1994 No 64

"Propulsion by Gyro", Eric Laithwaite, Space, Sep 1989 Vol 5 No 5 In an attempt to reveal the strange, hidden properties of gyroscopes, Professor Eric Laithwaite explains the physics behind the idea that a propulsion system could be built using gyros. -------------------------------
----

"Negative Mass in General Relativity", H. Bondi, Reviews of Modern Physics, Vol 29, July 1957, pp 423-428

"Looking for New Gravitational Forces with Antiprotons", M.M. Nieto and B.E. Bonner, Proceedings RAND Workshop on Anti Proton Science and Technology, World Scientific, Singapore, 1988 pp 328-341

"Negative and Imaginary Proper Masses", Y.P Terletskii, Paradoxes in the Theory of Relativity, Plenum, New York 1968, Chapter VI pp 83-115

"Gravitational Coupling of Negative Matter", A. Inomata and D. Peak, Nuovo Cimento, Vol B63 Sep 1969 pp 132-142

"Negative-Mass Lagging Cores of the Big Bang", B.D. Miller, Astrophysical Journal, Vol 208, Sep 1976 pp 275-285

"The Cosmological Term, the Shielding of Gravitation and the Negative Mass Hypothesis", A.A. Baranov, Izvestiya VUZ Fizika, Vol 14 Nov 1971 pp 118-120

"Negative Masses and the Energy-Sources of the Universe", Y.P. Terletskii, Experimentelle Technik der Physik, Vol 29 April 1981 pp 331-332 --------------
----

ELECTROMAGNETIC-GRAVITATIONAL CONVERSION CROSS SECTIONS IN EXTERNAL ELECTROMAGNETIC FIELDS International Centre for Theoretical Physics, Trieste (Italy). LONG, HOANG NGOC SOA, DANG VAN TRAN, TUAN A. SEP. 1994 11 PAGES DE95-613589 IC-94/285 Avail: CASI HC A03/MF A01 (US Sales Only) The classical processes: the conversion of photons into gravitons in the static electromagnetic fields are considered by using Feynman perturbation techniques. The differential cross sections are presented for the conversion in the electric field of the flat condenser and the magnetic field of the solenoid. A numerical evaluation shows that the cross sections may have the observable value in the present technical scenario. CASI Accession Number: N95-30637

I have an excerpt from a paper presented under the auspices of Northrop Corp. in 1968 that gives an idea of why you would want to bother with high voltage fields. To achieve the effects described involved relatively small high voltage. The true electrogravitational effects are significant at higher E field strength. In any case, this was only the state of the art in 1968. Their involvement in the B-2 began much later, after considerably more research.

Electroaerodynamics In Supersonic Flow
by M. S. Cahn and G. M. Andrew, Northrop Corporation, Hawthorne, California Presented at AIAA 6th Aerospace Sciences Meeting, January 22-24, 1968 - Tom Capizzi (tcapizzi@world.std.com)

ELECTRO-AERODYNAMICS: Electric charges are applied to high-speed vehicles for the purpose of reducing air drag or eliminating sonic booms. High-speed ions are projected forward from the leading edges of the craft, the corona glow propagates forward and repels air molecules away from the oncoming surfaces, thus a shock wave cannot be mechanically produced.

Sources: Dudley, Horace C., Analog Science Fact & Fiction. "The Electric Field Rocket", November 1960.

Product Engineering. "Sonic Boom Experiments", Vol. 39, New York, pp. 35-6, March 11, 1968.

US Patent No. 3,095,167, Dudley.

The paper entitled the "U.S. Antigravity Squadron" paper appears with others in the book "ELECTROGRAVITICS SYSTEMS: Reports on a New Propulsion Methodology" edited by Thomas Valone (Washington, D.C.: Integrity Research Institute, 1994); ISBN 0-9641070-0-7.

In addition to this paper, this book also includes the following:

1) The 1956 paper "Electrogravitics Systems" (prepared by the Special Weapons Study Unit of Aviation Studies Ltd., a UK-based aviation industry intelligence firm). It was declassified from a confidential status some time prior to 1985 and entered the public domain as a result of a request I placed through the Wright-Patterson Air Force Base Technical Library.

2) The 1956 paper "The Gravitics Situation" (prepared by Gravity Rand Ltd., a division of Aviation Studies Ltd. This includes six appendices with papers by various authors including the text from T. Townsend Brown's 1929 gravitor patent.

3) A paper by Banesh Hoffman entitled "Negative Mass as a Gravitational Source of Energy in the Quasistellar Radio Sources.

4) A collection of diagrams copied from various patents by T. Townsend Brown.

You may order a copy from:
Starburst Publications, 1176 Hedgewood Lane, Schenectady NY 12309, USA

Also available from Starburst Publications is the book "Subquantum Kinetics: The Alchemy of Creation" (ISBN 0-9642025-0-6). Subquantum kinetics is a new approach to microphysical theory that utilizes concepts from the fields of nonlinear chemical kinetics, irreversible thermodynamics, and general system theory, replacing the current mechanistic foundation of physics with a reaction-kinetic model. This new approach resolves a number of problems that plague classical and modern physics also may provide some insights into the electrogravitic connection that Brown was researching. In particular, chapter 9 gives some background information on Townsend Brown's electrogravitics.

Scott, W.B. "Black World engineers, scientists encourage using highly classified technology for civil applications." Aviation Week & Space Technology, March 9, 1992, pp. 66,67.

Brown, T.T. "How I Control Gravity." Science and Invention Magazine, August 1929. Reprinted in Psychic Observer 37(1) pp.14 - 18.

Burridge, G. "Another Step Towards Antigravity." The American Mercury 86(6) (1958):77 - 82.

Sigma, Rho, "Ether Technology: A Rational Approach to Gravity Control." Lakemont, GA: CSA Printing & Bindery, 1977, p. 44-49, quoteing a letter from T. Townsend Brown dated February 14, 1973.

Intel. "Towards Flight Without Stress or Strain...Or Weight." Intervia Magazine 11(5) (1956):373-374

Rose, M. "The Flying Saucer: The Application of the Biefeld-Brown Effect to the Solution of the Problems of Space Navigation." University for Social reesearch, April 8, 1952.

LaViolette, P.A. "An Introduction to Subquantum Kinetics: Part Journal of General Systems, Special Issue on Systems Thinking in Physics" 11(1985):295-
328.

LaViolette, P.A. "Subquantum Kinetics: The Alchemy of Creation." Schenectady, NY, 1994.

LaViolette, P.A. "Beyond the Big Bang: Ancient Myth and the Science of Continuous Creation." Rochester, VT:Inner Traditions Intl., 1994.

LaViolette, P.A. "A Theory of Electrogravtics." Electric Spacecraft Journal, Issue 8, 1993, pp. 33 - 36.

LaViolette, P.A. "A Tesla Wave Physics for a Free Energy Universe." Proceedings of the 1990 International Tesla Symposium, Colorado Springs, CO: International Tesla Society, 1991, pp. 5.1 - 5.19.

Aviation Studies (International) Ltd. "Electrogravitic Systems: An Examination of Electrostatic Motion, Dynaimc Counterbary and Barycentric Control." Report GRG 013/56 by Aviation Studies, Special Weapons Study Unit, London, February 1956. (Library of

Congress No. 3,1401,00034,5879; Call No. TL565.A9).

LaViolette, P. "Electrogravitics: Back to the Future." Electric Spacecraft Journal, Issue 4, 1992, pp. 23 - 28.

LaViolette, P. "Electrogravtics: An Energy-Efficient Means of Spacecraft Propulsion." Explore 3 (1991): 76 - 79; idea No. 100159 submitted to NASA's 1990 Space Exploration Outreach Program.

Aviation Studies (International) Ltd. "The Gravitics Situation". prepared by Gravity Rand Ltd. - a divison of Aviation Studies, London, December 1956.

Northrup Studying Sonic Boom Remedy." Aviation Week & Space Technology, Jan. 22, 1968, p.21.

Rhodes, L. "Ex-NASA Expert Says Stealth Uses Parts from UFO." Arkansas Democrat, Little Rock, AR., April 9, 1990.

Scott, W.B. "Inside the Stealth Bomber" Tab/Aero Books: New York, 1991.

One of the most famous researchers in this area is John Searl, who noticed that spinning metal would accumulate electrons on the rim, possibly through some kind of centrifugal thrust. The initial test was a metal disk attached to a breakaway coupling driven by a gasoline engine. It was carried out in the country and as the disk reached higher and higher speeds, tremendous electrostatic forces were generated which were estimated at 10 to the 6th volts! That's when the disk began to glow blue, broke the coupling, rose to about 30 feet, continued to accelerate, turned pink and shot off into space. Searl claims this happened with many of his early tests and as a result he lost the device each time. Later he learned how to control the device. The neat thing about it, the Searl disk is self-propelling using a magnetic drive.
-- Jerry Decker

THE SEARL EFFECT
(The Introduction)
[To contact WCVE write to:
23 Sesame Street
Richmond VA, 23235
or phone: 804-320-1301
or fax: 804-320-8729]

ANTIGRAVITY: The Dream made Reality
[The Story of John R. R. Searl]
by John A. Thomas Jr.
Published by Direct International Science Consortium 13 Blackburn, Low Strand, Grahame Park Estate, London NW95NG England

Available in this country through John A. Thomas, Jr. 373 Rock Beach Rd.
Rochester, NY 14617-1316
Phone: (716) 467-2694

Thomas, John A., Jr.
Antigravity : the dream made reality : the story of John R.R. Searl / by John A. Thomas Jr. London : Direct International Science Consortium, c1993. 1 v. (various pagings) : ill. (some col.) ; 28 cm. LC CALL NUMBER: QC178 .T46 1993
SUBJECTS: Searl, John R. R. (John Roy Robert), 1932-. Antigravity. ISBN: 1898827990 (spiral)

NEXUS Magazine
Volume 2, Number 17
P.O. Box 177
Kempton, IL 60946
Phone: (815) 252-6464
Fax: (815) 253-6300

Extraordinary Science
Volume VI. Issue 2
ISSN 1043-3716

Aspden, Harold A. (1989). "The Theory of the Gravitation Constant," Physical Essays, Vol. 2, No. 2, pages 173-179.

Aspden, Harold A. (1991). "The Theory of Antigravity," Physical Essays, Vol. 4, no. 1, pages 13-19.

Electrogravitic Systems: Reports on a New Propulsion Methodology by Thomas Valone, M.A., P.E.

The Anti-Gravity Handbook
by D. Hatcher Childress

Ether-Technology: A Rational Approach to Gravity-Control by Rho Sigma

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Sigma, Rho.
Forschung in Fesseln : das Ratsel d. Elektro-Gravitation / von Rho Sigma. Wiesbaden-Schierstein : Ventla-Verl., 1972. 272 p. : ill. ; 21 cm. LC CALL NUMBER: TL789 .S524 1972
SUBJECTS: Unidentified flying objects. Gravitation. ISBN: DM24.00

There is also a good book written by an Aerospace Engineer who worked for General Electric, named John Ackerman. The book is called "To Catch a Flying Star". It is available from Univelt, Inc., P.O. Box 28130, San Diego, CA. 92128 ISBN 0-912183-03-9.

AUTHOR: Ackerman, John.
TITLE: To catch a flying star : a scientific theory of UFOs / by
John Ackerman ; with a forward by Walter H. Andrus, Jr. PUBL.: San Diego, Calif. : Univelt,
DATE: 1989
SUBJECT: UNIDENTIFIED FLYING OBJECTS, SPACECRAFT, UFOs, INTERSTELLAR SPACECRAFT, INTERSTELLAR TRAVEL LONG DURATION SPACE FLIGHT, ASTRONAUTICS FLIGHT CONTROL
ISBN: 0912183039 (pbk.)

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PO Box 11422 to the pioneering work of several sci-
Clearwater FL 34616 entists and inventors, including Nikola
Suscription info:$35, 4 issu/yr Telsa, Viktor Schauberger, T. Henry Moray, Editors: Donald A. Kelly T.T. Brown, Alfred Hubbard, T.J.J. See,
Michael MarinoErwin Saxl, Hans Coler and others.
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"Antigravity" by R.M. Santilli
The Institute for Basic Research,
PO Box 1577
Palm Harbor FL 34682

Recently I had read a book from Hans A. Nieper with the title "Konversion von Schwerkraft-Feld-Energie" (transformation of gravity field energy). This book tells from transformers of the types Fluxtransformer (electrodynamic system) and Capacitor Discharge (solid state method). My problem is that I find nowhere informations about these machines. So I hope that YOU can give me hints whre I can find informations (books, files,articles ...) about these machines and theories. I am also grateful for your opinions about these theory and these machines. -- Michael Bell Berlin, Germany

Revolution in Technik, Medizin, Gesellschaft. English. Revolution in technology, medicine and society : conversion of gravity field energy / Hans A. Nieper. Extended ed. in English, 1. ed. Oldenburg : MIT Verlag, 1985. 384 p. : ill. ; 22 cm.
LC CALL NUMBER: TJ163.7 .R4813 1985
SUBJECTS: Power (Mechanics)--Congresses. Translation of: Revolution in Technik, Medizin, Gesellschaft. Cover title: Dr. Nieper's Revolution in technology, medicine, and society. Includes proceedings of the Symposium on Energy Technology, Hannover, Nov. 27-28, 1980, and the First International Symposium on Non-Conventional Energy Technology, Oct. 23-24, Toronto, Oct. 23-
24, 1981. ISBN: 392518807X

Nieper, Hans A. Zur Theorie der Schwerkraftwirkungen. In "Revolution in Technik Medizin Gesellschaft",

Bearden, T. E. Maxwell's lost Unified Field Theory of Electromagnetics and Gravitation. In "New Energy Technology", pg. 25. Published by The Planetary Association for Clean Energy, nc. Ottawa/Hull, Canada.

Bearden, Thomas E. (1988). "Maxwell's Original Quaternion Theory Was a Unified Field Theory of Electromagnetics and Gravitation," Proceedings of the International Tesla Society, 1988, ITS Books.

Moretti, Angelo. Possibility of Non-Zero Mass in Synchrotron Radiation. In "What Physics for the next century?" pg. 397 - Inediti No. 59, Societ_Editrice Andromeda, Bologna

Gunnufson, Craig. Neuere Neutrinomessungen aus der Sonne unterstuetzen eine neue Theorie. Lecture held at a congress on Gravity Field Energy in Toronto, Oct. 1981. In Nieper, "Revolution in Technik Medizin Gesellschaft", Illmer Verlag, Hannover

Seike, Shinichi. Lecture held at Energy Symposium in Hannover, November 1980. In Nieper, Revolution in Technik Medizin Gesellschaft. ----------------------

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Anyone ever see Stan Deyo's book Cosmic Conspiracy? He talked about an ElectroGravitics society I think it was.

These things must have some sort of high voltage resonating circuitry, in a round shape obviously. They can recharge over high power lines. They can apparently become invisible. They also must be able to change their mass so they can accelerate at very high rates.

For anyone interested, he wrote a second book called "The Vindicator Scrolls" which contains more information.

"Space Warps: A Review of One Form of Propulsionless Transport," _Journal of the British Interplanetary Society_ 42 (Nov. 1989): 533-542.

"Negative Matter Propulsion," _Journal of Propulsion and Power_ 1 (Jan.-Feb. 1990): 28-37.

Vonsovskii, S, Ferromagnetic Resonance, 1966. Feynman, R, Feynman Lectures on Physics, v2, 1964 Chikazumi, S, Physics of Magnetism, 1964 Soohoo, R,
Microwave Magnetics, 1988
Herlach, F, Strong and Ultrastrong Magnetic Fields, 1985 ---------------------
----

[1] The Feynman Lectures on Physics, 1963, v1 chp13 p8.

[2] Bottcher, C., Theory of Electric Polarization, 1973, v1 pp71,289.

[3] Albert Einstein: Philosopher-Scientist, 1949, pp522-523.

Feynman's Lectures Vol II Chapter 10, Page 10-8, describes an electrostatic effect that may be related to the Biefeld-Brown effect. Feynman shows that a force results on a dielectric due to the gradient of the square of the electrical field.

There have been quite a few people who have also looked at 'gravitationless' universes, such as:

Ralph Juergens, 'Reconciling Celestial Mechanics', Pensee Fall 1992. C E R Bruce, A New Approach to Astrophysics and Cosmogony, London 1944 Problems of Atmospheric and Space Electricity, Elsevier, 1965 Eric Crew, Electricity in Astronomy, SIS Review, Vol 1 No 1-4. Earl Milton, Electric Stars in a Gravity-Less Electrified Cosmos SIS Review, Vol V, No 1.

Ian Tresman
London, UK

AUTHOR: Driscoll, R.B.
TITLE: Comments on the paper "Gravitational lift via the
Coriolis force" by Leon R. Dragone.
In: Hadronic journal.
JUL 01 1988 v 11 n 4 Page: 177

Paper: gr-qc/9503060
From: linet@ccr.jussieu.fr (Bernard LINET) Date: Thu, 30 Mar 1995 14:55:07 +0200
Title: Vacuum polarization induced by a uniformly accelerated charge Author: B. Linet
Report-no: GCR-941003
We consider a point charge fixed in the Rindler coordinates which describe a uniformly accelerated frame. We determine an integral expression of the induced charge density due to the vacuum polarization at the first order in the fine structure constant. In the case where the acceleration is weak, we give explicitly the induced electrostatic potential.

Paper: gr-qc/9504023
From: Mathias PILLIN Date: Mon, 17 Apr 1995 10:43:50 +0900
Title: Pure spin-connection formulation of gravity and classification of energy-momentum tensors
Author: Mathias PILLIN
Report-no: YITP/U-95-12
It is shown how the different irreducibility classes of the energy-momentum tensor allow for a pure spin-connection formulation. Ambiguities in this formulation especially concerning the need for constraints are clarified.

Paper: gr-qc/9504041
From: SHORE@crnvma.cern.ch
Date: Tue, 25 Apr 95 17:22:56 SET
Title: ``Faster than Light'' Photons in Gravitational Fields -- Causality, Anomalies and Horizons
Authors: G.M. Shore
Report-no: SWAT-95/70
A number of general issues relating to superluminal photon propagation in gravitational fields are explored. The possibility of superluminal, yet causal, photon propagation arises because of Equivalence Principle violating interactions induced by vacuum polarisation in QED in curved spacetime. Two general theorems are presented: first, a polarisation sum rule which relates the polarisation averaged velocity shift to the matter energy-momentum tensor and second, a `horizon theorem' which ensures that the geometric event horizon for black hole spacetimes remains a true horizon for real photon propagation in QED. A comparision is made with the equivalent results for electromagnetic birefringence and possible connections between superluminal photon propagation, causality and the conformal anomaly are exposed.

Paper: hep-th/9506035
From: Gary Gibbons Date (revised): Sun, 27 Aug 95 11:31:39 BST Title: Electric-Magnetic Duality Rotations in Non-Linear Electrodynamics

Authors: G W Gibbons, D A Rasheed -- To appear in Nucl Phys B Report-no: DAMTP preprint # R95/46.
We show that there is a function of one variable's worth of Lagrangians for a single Maxwell field coupled to gravity whose equations of motion admit electric-magnetic duality.

Paper: gr-qc/9506053
From: ESPOSITO@napoli.infn.it
Date: Mon, 26 Jun 1995 10:24:36 +0200 (CET-DST) Title: Euclidean Maxwell Theory in the Presence of Boundaries Author: Giampiero Esposito
Comments: 18 pages, plain-tex, to appear in: Heat-Kernel Techniques and Quantum Gravity, Discourses in Mathematics and Its Applications, No. 4, edited by S.A. Fulling (Texas A&M University, College Station, Texas, 1995)
Report-no: DSF preprint 95/31
This paper describes recent progress in the analysis of relativistic gauge conditions for Euclidean Maxwell theory in the presence of boundaries. The corresponding quantum amplitudes are studied by using Faddeev-Popov formalism and zeta-function regularization, after expanding the electromagnetic potential in harmonics on the boundary 3-geometry. This leads to a semiclassical analysis of quantum amplitudes, involving transverse modes, ghost modes, coupled normal and longitudinal modes, and the decoupled normal mode of Maxwell theory.

Paper: gr-qc/9507050
From: Luis Octavio Pimentel Date: Tue, 25 Jul 1995 11:19:44 -0500 (CDT) Title: Electromagnetic Field in Some Anisotropic Stiff Fluid Universes Authors: Pimentel L O
Report-no: UAMI-AG-95-29
The electromagnetic field is studied in a family of exact solutions of the Einstein equations whose material content is a perfect fluid with stiff equation of state (p = $\epsilon $). The field equations are solved exactly for several members of the family. --
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El Escorial Summer School on Gravitation and General Relativity 1992: Rotating objects and relativistic physics: Proceedings of the El Escorial Summer School on Gravitation and General Relativity (1992) Held at El Escorial, Spain, 24-28 August 1992 / F.J. Chinea, L.M. Gonzalez-Romero, eds. Berlin ; New York : Springer-Verlag, c1993. 302p. LC CALL NUMBER: QC178 .E36 1992
SUBJECTS: Gravitational fields. General relativity. Astrophysics Chinea, F. J. (Francisco Javier), 1949-
Gonzalez-Romero, L. M. (Luis Manuel), 1962-
ISBN: 354057364X (Berlin : acid-free paper) : DM90.00 038757364X (New York : acid-free paper) : $62.00 -----------------------------
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"Propulsion Techniques: Action and Reaction", Peter J. Turchi, editor, Ohio State University This is the first of three volumes devoted to space propulsion part of a new series of titles with articles taken from the pages of Aerospace America. The three volume collection of over 150 articles rescues the insights, concerns and dreams of dozens of space propulsion experts for the next generation of aerospace scientists and engineers. Written by well-known figures in space propulsion, including Werner von Braun, Martin Summerfield, Ernst Stuhlinger and Jerry Grey, these books provide readily accessible source material for design courses in astronautical engineering. This first volume surveys the technologies of rocketry in the traditional categories of liquid, solid, hybrid, nuclear and electric propulsion. Historical trends and cycles are displayed in each category as articles describe concepts and progress from the early visions of Goddard, Oberth and Tsiolkovsky to proposed (and re-proposed) ideas for advanced space thrusters. In addition to descriptions of rocket engines of various types, including photon and laser propulsion, associated technologies for propellants and space-electrical power systems are discussed.

Spring 1995, 350 pp, illus, Paperback

ISBN 1-56347-115-9
(Available from the AIAA)

I have a book from Russia that may interest you. Its in Russian and its called "Experimental Gravity", and is jointly authored by a father and son, S.M. Poliakov and O.M. Poliakov. It describes "gyro-gravity" and "ferromagnetic-
gravity" and also how to produce gravity. It's 130 pages and contains a lot of pictures and diagrams and equations (that's about all I understand from it). To judge from the pictures the Russians must have conducted a lot of research in this topic (Many different devices are on the pictures). The question is now: How do I get a translator? -- David Jonsson
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INTRODUCTION TO EXPERIMENTAL GRAVITONICS Abstract of book by S.M.Poliakov and O.S.Poliakov

The experiments part covers the following subjects: 1. Light-beam curvature and optical-radiation frequency shift is created and investigated in an artificial nonhomogeneous gravitational field.
A new gravitational effect, named "quadrature" frequency shift in the curved light beam is predicted and calculated. 2. Magnetostriction is at last explained as a secondary gravitational effect. An equation derived for magnetostriction permits to calculate the magnetostriction curve.
3. The propagation velocity of gravitational radiation (generated by a laboratory source) was measured for "quadrupole" - 9x10E20 cm/s or squared light velocity.
4. It was demonstrated that gravitation is only one of NONLINEAR-MECHANICS EFFECT, that can be created in mechanical system or in ferromagnetic.

The book was published at the author's expense in 1991. Most powerful experimental result described in this book is more than 1200 gramms of pulsed G-force. Several mechanical systems and systems using ferrites are detailed here.

Second edition in English is ready for copy process (disket's text). Editors and investors are interested in joint project for publication can get direct contact with Dr. Poliakov by address: Moscow area, 141120, FRIAZINO, 60-let str., 1-167. Phone 7-095-4658822.

Alexander V. Frolov
P.O.Box 37, St.-Petersburg, 193024, Russia. E-mail: alex@frolov.spb.ru -------------------------
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Super-weapon designer Edward Teller has written an article entitled: "Electromagnetism and Gravitation", Proc. Nat. Acad. Sci. USA Vol 74, No 4. P. 2664-2666. Teller's article is referenced in the book by the Poliakov brothers about Russian experiments in gravitation control. ---------------------------
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I wrote already about Poliakov's book "Experimental Gravitonics". He wrote it in 1991 and published in Russian. Now he have English version as MSDOS text on diskett. If you wish help for Dr.Poliakov, write for him and buy book in Russian or copy of text in English. Here is more information.
-- Alex Frolov

"Experimental Gravitonics" Spartak M. Poliakov, Oleg S. Poliakov Russia 141120 Moscow area, Friazino, 60-let SSSR str., 1 - 167.

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1. H.E.Puthoff, The energetic vacuum: implications for energy research, Speculations in science and technology, vol.13, No.3, p.247.

2. Thomas Valone, Inertial propulsion... Newsletter of Planetary Association for Clean Energy, vol.7 No.1, p.6-12. Published by PACE, Inc. 100 Bronson Av.,Suite 1001, Ottawa, Ontario K1R 6G8, Canada.

3. Re NASA electrostatic levitation experiments and Thomas Townsend Brown's research look the Newsletter of Planetary Association for Clean Energy, vol.7 No.4.p.7. July, 1994. "Electrogravitics developments" reprinted from NEXUS Special.

4. "The Swiss Methernitha-Linden Converter", p.3-6. Space Energy Newsletter, June 1993, vol.4 No.2. Published by Space Energy Association, P.O.Box 11422, Clearwater, FL 34616, USA. My understanding of this electrostatic machine allows development of a simple scheme: self-rotating thanks to electrostatic forces disk and ordinary electrical generator connected with axis of disk.

5. Conception of Edmund Whittaker (papers of 1903-1904) is developed by T.E.Bearden in his book "Gravitobiology", published by Tesla Book Co., P.O.Box 121873, Chula Vista, CA 91912, USA.

6. P.D. Ouspensky, A New Model of the Universe, New York, 1971.p.433 in Russian edition of 1993.

7. Example of joint demonstration of "gravity/chronal/over-unit power" effect is invention of Ivan Stepanovitch Filimonenko of 1960. His version of cold fusion system produced: 1. Heat power 2. Motive force without fling back of mass 3. Influence on time-period of half-decay. Article of N.E.Zaev published in "Izobretatel i Razionalizator", Russia, No.1 1995, p.8-9.

8. Alexander V. Frolov, The Application of Potential Energy for Creation of Power, New Energy News, vol.2, No.1, May 1994. Published by Institute for New Energy, P.O.Box 58639, Salt Like City, UT 84158-8639, USA.

9. V.V.Lensky, General for Many-Polarity, Irkutsk, Russia, 1986. Published in Russian by Irkutsk University.

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= BEARDEN, THOMAS E., AND WALTER ROSENTHAL (1991). "ON A TESTABLE UNIFICATION OF ELECTROMAGNETICS, GENERAL RELATIVITY, AND QUANTUM MECHANICS," 26TH IECEC, VOL. 4, PAGES 487-492, AND ASSOCIATION OF DISTINGUISHED AMERICAN SCIENTISTS.

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VALONE, THOMAS (1991). "THE ONE-PIECE FARADAY GENERATOR: RESEARCH RESULTS," 26TH IECEC, VOL. 4, PAGES 473-478. ---------------------------------
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AUTHOR :Znidarsic, Frank
TITLE :Elementary antigravity / Frank Znidarsic. LANGUAGE :ENGLISH
PUBLISHED :New York : Vantage Press ; 1989 PHYSICAL DESC :53 p. ; 21 cm.
SUBJECT :Gravitation, Antigravity

Title: THE SOURCE OF INERTIAL AND GRAVITATIONAL MASS Author: Frank

Znidarsic P.E. FZNIDARS@GPU.COM, ELECTRICAL ENGINEER WITH THE PENN ELECTRIC CO. JOHNSTOWN, Pa. COMMENTS: 8 PAGES ASCII TXT FILE. NEW ENERGY PROJECT, Submitted to the Canadian Journal of Physics, July 94 resubmitted Jan 95 Texted in the DOS editor. (Available at Elektromagnum web site)

Title: GENESIS OF AND ZERO POINT ENERGY
Author: FZNIDARSIC@GPU.COM, F. Znidarsic Electrical Engineer with the Pennsylvania Electric Co. Johnstown Pa. Comments: ASCII *.TXT, 5 PAGES, Texted on DOS editor submitted to the Canadian Journal of Physics July 94, Resubmitted Jan 95 Report_no: Special Energy Prog. (Available at Elektromagnum web site)

The Jackson text is entirely wrong if it does discuss magnetic fields without a potential - the electromagnetic 4-potential A always applies to the conservation of 4-momentum (energy and momentum) by electromagnetic interactions.

See GRAVITATION by Misner, Thorne, and Wheeler. ------------------------------
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The causative agent of gravitational gradients (Potential) was first enumerated G. L. Le Sage in 1784. H. A. Lorentz and G. H. Darwin evaluated Le Sage's postulate mathematically and rejected it when, as a result of their evaluation, it was found that although the postulated process could describe all observed gravitational phenomena (and inherently results is GR), the mechanism REQUIRED a continuous overall LOSS of energy (apparently disappearing into matter, in a clear violation of the conservation of energy). I could go on to suggest that mining this concept and process could lead one to significant "pay dirt" in terms of understanding how GR relates to QM.

The kinetic model of Le Sage does lead to a valid model for physical processes. The key is Super-Fluid theory. Both GR and QM are fully described as well as why each dominates at the scales they do. Hemholtz proved that a superfluid vortex ring is infinitely stable and without a boundary dis-
continuty can not be created or destroyed. Kelvin mathematically proved that the equations that describe small linear disturbances in a a superfluid vortex sponge are IDENTICAL to the equations that describe the propogation of light through space. A EXCELLENT book on this topic is "A History of the Theories of Aether and Electricity" by Sir Edmund Whitaker, Dover Reprint 1989 and I can not give any reference a higher recommendation. Why is this information not known, that sir is a very long and interesting story. - Paul Stowe
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For a much more current model, than LeSage, of a sink-source interpretation of gravity, see O.C. Hilgenberg's "Gravitation, Tromben, und Wellen in bewegten Medien" (1931), GieSmann & Bartsch. It's in German. It's in the National Union Catalogue. If you don't read German, then Carl Frederick Krafft's "Ether and Matter" (1945), Dietz Printing Co., contains some portions translated from Hilgenberg's work. Hilgenberg developed a quantum numbering system of the atoms based upon Krafft's ether-vortex atom model, entitled "Quantenzahlen, Wirbelring-Atommodelle und Heliumsechserring- Aufbauprinzip des Periodensystems der chemischen Elemente" Which means roughly: A Quantum Number, Vortex Atom model and Hexagonal-ring construction principle of the periodic system of the chemical elements. Krafft saw the quantization of energy as a logical consequence of a system of particles consisting of, basically, pumps, which could take in and give out energy and ether/space at limited rates, based on rotations of the various rings.

In his model, as opposed to LeSage's, the flux terminates in what he called equipotential zones, much as one would see if two jets of water were to collide coaxially. So, the intake of two bodies "squirting" out ether, will be on the back sides of both bodies, and hence, they are pushed together. LeSage saw each body acting as sheilds to the ultramundane particles racing in all directions in space (cosmic rays forseen in the 18th century!) Thus the two bodies move into each others 'shadow'.

Louis Kevran's work on low energy transmutations of the elements was predicted by Krafft's model. And there was a man named Nemos who claimed to have developed a television type microscope not limited by the optical paths of standard microscopes, and I have a photo he took which shows, it is claimed, the nucleous of an iron atom, as a collection of vortices arranged peripherally (non-coaxially). It's like looking down on pearl-like smoke rings connected by vibrating jets. It's an amazing photo(?) Krafft's prediction was that the proton and electron would be double vortex structures, and the neutron a triple vortex structure. The picture seems to confirm that. So much for my two bits. The work of Krafft is not heavily laden with math. The beauty of it to me is it can be visualized. (Note: Nemo's "microscope" may be based on the technology very recently developed which is known as magnetic microscopy.)

I have a neat little book written by Carl Krafft, back in the 30s. He was an avid developer of an ether-vortex theory of atomic and gravitational forces. His theory was underpinned by the writings of O.C. Hilgenberg and Hermanne Fricke of Germany, pre-Nazi. Hilgenberg's views included a vertical ether sink as the cause of gravity, and the consequent development of mass in the enterior of the earth. Hence the earth expanded over time, with periodic explosive expansions and contractions. Meanwhile, Krafft developed the idea of combining vortices in face to face rolling contact, which provides four basic forms: single vortice=neutrino; double vortice, with rolling contact drawing ether into the periphery-proton; with rolling contact into the poles-electron; then the neutron which is three vortices combining forming a neutral, polarizeable particle drawing ether into one end, out the sides, in the sides out the other end. Krafft's books were all self published.
-- Roger Cathey

Is there anyone out there who is familiar with modern Kaluza-Klein theory? Or even with the kind Kaluza got Einstein to buy into in 1921 or whenever it was...? This is supposed to unify gravity and electromagnetics in a five-dimensional model. Would it not predict the kind of effects Brown was experimenting with, if true?
-John Sangster

Kaluza and Klein had the idea of extending GR to 5 dimensions. When they did Maxwell's eqns. just sort of pop out. Unfortunately the weak and strong nuclear forces don't. So people try expanding GR into 10, 11 or even 26. It's interesting to do the reverse. Expand Maxwell's eqns. into 5 dimensions. I did it and soon I'll (hopefully) give some details. But essentially you get two out of three of Newton's gravitational equations. You get something similar to the third eqn. but I haven't convinced myself that mine is a generalization of Newton's.
-Ray Cote, KSC

Kaluza-Klein theories are an attempt to give a general relativistic explaination for all the forces of nature not just gravity. The original Kaluza-Klein idea was hatched in 1920 by Kaluza and in 1926 by Klein. The basic idea is that there are 4 space dimensions and 1 time dimension (a 5 dimensional maifold) rather than the 3 space dimensions and 1 time dimesnions that there appear to be. Then generalizing Einsteins field equations to this 5 dimensional space (and making the assumption that one of the dimensions gets "curled" up or "compactified") you find that you get Einsteins 4D field equations plus Maxwell's equations. The way that this happens is one of the most beautiful aspects of this theory, and it really makes you (or at least it makes me) think that there should be at least some aspect of this theory that has some correspondence in reality.

Kaluza-Klein theories were revived in the mid seventies by A. Chodos (I think) who showed how you can incorparte all the interactions that we know about now (the strong and the weak forces which weren't unified with gravity in Kaluza's original theory, which only unified EM and gravity) by taking spacetime to be 11 dimensional (10 space dimensions and 1 time).

I can't really think of a good laymans intro to Kaluza-Klein, but there is a Physics Report in 1985 and 1986 that gives a review of Kaluza-Klein theories by Bailin and Love (?). And there is a Frontiers of Physics book edited by T. Appelquist which reprints most of the important articles on the subject. - Doug Singleton

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"The Possibly Unifying Effect of the Dynamic Theory", May 1983, by P.E. Williams
This is part of a series of works by Williams. The novel aspect of the work it that Williams starts from thermodynamics instead of the usual general relativistic and Newtonian approach. Williams develops the 5-D field equations and the neo-coulombic potential. The equations allow for inductive coupling between the electric and gravitational fields.
-- Dennis Cravens

Kaku, Michio.
Hyperspace : a scientific odyssey through parallel universes, time warps, and the 10th dimension / Michio Kaku. New York : Oxford University Press, LC CALL NUMBER: QC793.3.F5 K35 1994 *CIP SUBJECTS: Kaluza-Klein theories. Superstring theories. Hyperspace. ISBN: 0195085140 (alk. paper)

THE INTERACTION OF MAGNETIZATIONS WITH AN EXTERNAL ELECTROMAGNETIC FIELD AND A TIME-DEPENDENT MAGNETIC AHARONOV-BOHM EFFECT Joint Inst. for Nuclear Research, Dubna (USSR). AFANASEV, G.N. NELHIEBEL, M. STEPANOVSKIJ, YU. P. AB(Technische Univ., Vienna, Austria.) AC(Academy of Sciences of the Ukraine, Kharkov, Ukraine.) 1994 20 PAGES DE95-613463 JINR-E-2-94-297 Avail: CASI HC A03/MF A01 (US Sales Only) We investigate how the choice of the magnetization distribution inside the sample affects its interaction with the external electromagnetic field. The strong selectivity to the time dependence of the external electromagnetic field arises for the particular magnetizations. This can be used for the storage and ciphering of information. We propose a time-
dependent Aharonov-Bohm-like experiment in which the phase of the wave function is changed by the time-dependent vector magnetic potential. The arising time-dependent interference picture may be viewed as a new channel for the information transfer.
CASI Accession Number: N95-30368

AUTHOR :Doughty, Noel A. (Noel Arthur)
TITLE :Lagrangian interaction : an introduction to relativistic symmetry in electrodynamics and gravitation / Noel A. Doughty. PUBLISHED :Sydney ; Readwood City, Calif. : Addison-Wesley, c1990. DESC :xix, 569 p. : ill. ; 23 cm.
SUBJECT :Electrodynamics, Gravitation, Relativity, Symmetry ------------------

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GENERALIZED HALL ACCELERATION FOR SPACE PROPULSION SASOH, AKIHIRO AATohoku University, Sendai, Japan In: International Symposium on Space Technology and Science, 18th, Kagoshima, Japan, May 17-22, 1992. Vols. 1 & 2 . A95-82299 Tokyo, Japan ISTS Editorial Board 1992 6 PAGES 1992 p. 403-408
The operation characteristics of electric propulsion devices which utilize Hall effect have been generalized. The electrostatic acceleration is enhanced by thermoelectric effect; an ion kinetic energy can be higher than that associated with the electrostatic potential. Depending on the extent of this effect, there exist two acceleration modes, an electrostatic and an electrostatic/electrothermal hybrid one, the latter characterized by low voltage.

ABSTRACTS OF THE AMERICAN MATHEMATICAL SOCIETY:

vol. 12 (1991)p.572 Abstract *91T-81-200 by Alexander Abian: "The inertia of Time and the energy spent on moving Time forward"

vol. 13 (1992)p.344 Abstract *92T-81-79 by Alexander Abian: "The universal Time"

vol. 15 (1994)p.437 Abstract *94T-81-92 by Alexander Abian "Time has inertia. Equivalence of Time and mass"

vol. 15 (1994)p.585 Abstract *94T-81-164 by Alexander Abian "Time has inertia. Equivalence of Time and mass. How to measure the mass of Time"
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Look up a paper published by Miguel Alcubierre in Classical and Quantum Gravity 11 (1994) pp. L73-L77. It's titled "The Warp-Drive: Hyper-Fast Travel within General Relativity". If you can follow a lot of math (or at least the gist of it) it is fascinating. -Ian McBride

"The Warp drive: hyper-fast travel within general relativity" by: Miguel Alcubierre
Department of Physics and Astronomy, University of Wales, College of Cardiff, PO Box 913, Cardiff CFI 3YB, UK

Article taken from the May 1994 issue of "Classical and Quantum Gravity", a scientific magazine wich you are not likely to find at your local newsagent.

ABSTRACT. It is shown how, within the framework of general relativity and without the introduction of wormholes, it is possible to modify a spacetime in a way that allows a spaceship to travel with an arbitarily large speed. By a purely local expansion of spacetime behind the spaceship and an opposite contraction in front of it, motion faster than the speed of light as seen by observers outside the disturbed region is possible. The resulting distortion is reminicent of the 'warp drive' of science fiction. However, just as happens with wormholes, exotic matter will be needed in order to generate a distortion of spacetime like the one discussed here. -------
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Anomalous Info Nexus
S P A C E D R I V E S PO Box 228
Kingston Springs, TN
Introductory Reading List U S A 37O82-O228

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Electric Spacecraft Journal, 73 Sunlight Dr, Leicester, NC 28748, 704.683.0313 Voice / 704.683.3511 FAX / 615.952.5638 BBS Published since 1991, Quarterly, Subscription Rate: $24/Yr (Only U.S. publication dedicated to Space Drives R&D)

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S-751 06 UPPSALA Internet E-mail t89djo@tdb.uu.se SWEDEN ++++++Cold EMISSION before the end of the century++++++
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AUTHOR: Terletskii, IAkov Petrovich, 1912-
Paradoksy teorii otnositelnosti. Russian/English TITLE:Paradoxes in the theory of relativity, by Yakov P.
Terletskii. With a foreword by Banesh Hoffmann. PUBL.: New York, Plenum Press, 1968
NOTES: Translation of Paradoksy teorii otnositelnosti.

QUANTUM FLUCTUATIONS AND SEMICLASSICAL GRAVITY THEORY PH.D. THESIS Tufts Univ., Medford, MA. KUO, CHUNG-I. 1994, 119 PAGES Avail: Univ. Microfilms Order No. DA9419336 Semiclassical gravity theory should serve as a working model before the final theory of quantized gravity is known, or as an approximation for manageable calculations even when the final theory is known. We deal with the important issue of the applicability of the semiclassical theory of gravity, specifically considering the effects of quantum fluctuations of the matter fields and the induced metric perturbations. The quantum fields with negative energy densities are proposed to be the cases where the semiclassical theory is no longer valid. We start with a discussion of the basic notions and developments of semiclassical gravity theory, and continue with a discussion of the establishment of a meaningful measurement of the deviation from semiclassical theory. The measure is a normalized dispersion of the energy density. The non-positive-definiteness of the energy density of quantum fields is derived and discussed. Important cases, like squeezed states and the Casimir effect, which exhibit negative energy densities, are discussed and the deviations from semiclassical theory are checked. A test particle method using a generalized Langevin equation is formulated for the physical description of systems for which the semiclassical theory can not be used. Quantum fields around straight infinite cosmic string is another example of where the negative energy densities may arise. We examine the validity of semiclassical theory for this case. The Casimir force due to the zero-point fluctuations of the electromagnetic fields in the presence of a conducting plate is another case where the quantum fluctuations are large and naive classical consideration should be modified. Using the test particle method, we are able to show that it is a relaxation phenomenon and that a notion of effective temperature can be associated with it. CASI Accession Number: N95-29527

ELECTROMAGNETIC-GRAVITATIONAL CONVERSION CROSS SECTIONS IN EXTERNAL ELECTROMAGNETIC FIELDS International Centre for Theoretical Physics, Trieste (Italy). LONG, HOANG NGOC SOA, DANG VAN TRAN, TUAN A. SEP. 1994 11 PAGES DE95-613589 IC-94/285 Avail: CASI HC A03/MF A01 (US Sales Only) The classical processes: the conversion of photons into gravitons in the static electromagnetic fields are considered by using Feynman perturbation techniques. The differential cross sections are presented for the conversion in the electric field of the flat condenser and the

magnetic field of the solenoid. A numerical evaluation shows that the cross sections may have the observable value in the present technical scenario. CASI Accession Number: N95-30637

THE PHYSICS OF TACHYONS. 3: TACHYON ELECTROMAGNETISM DAWE, ROSS L. HINES, KENNETH C. University of Melbourne, Parkville, Australia 1994 34 PAGES Australian Journal of Physics (ISSN 0004-9506) vol 47, no 4 1994 p 431-464 Research supported by the ARC and the University of Melbourne HTN-95-01061
A new formulation of the theory of tachyons using the same two postulates as in special relativity is applied to electro-magnetism. Tachyonic transformations of the electromagnetic fields E and B are rigorously derived from Maxwell's equations and are shown to be the same as for bradyonic transformations. Tachyonic tranformations of current density, charge density, scalar and vector potentials are also derived and discussed. Tachyonic optics and the four-potential of a moving tachyonic charge are also discussed, along with generalized four-vector transformations and electromagnetic four-tensors in extended relativity. Use is made of a switching principle to show how tachyons automatically obey the law of conservation of electric charge in any inertial reference frame, even though the observed tachyon electric charge is not an invariant between observers. The electromagnetic field produced by a charged tachyon takes the form of a Mach cone, inside which the electromagnetic field is real and detectable, while outside the cone the field generated by the tachyon is imaginary and undetectable.
CASI Accession Number: A95-90247

Franklin, Allan, 1938-
The rise and fall of the "Fifth Force" : discovery, pursuit, and justification in modern physics / Allan Franklin. New York : American Institute of Physics, c1993. 141 p. : ill. ; 25 cm. LC CALL NUMBER: QC6 F673 1993
SUBJECTS: Physics--Methodology. Gravitation.

Michlo, George, 1942-
The push of gravity / George Michlo ; illustrated by Warwick Humphries. 1st ed. New York : Vantage Press, c1993. xv, 101 p. : ill. ; 24 cm. LC CALL NUMBER: QC178 .M49 1993
SUBJECTS: Gravitation.
ISBN: 0533091330

Doughty, Noel A. (Noel Arthur)
Lagrangian interaction : an introduction to relativistic symmetry in electrodynamics and gravitation / Noel A. Doughty. Sydney ; Readwood City, Calif. : Addison-Wesley, c1990. xix, 569 p. : ill. ; 23 cm. LC CALL NUMBER: QC631 .D68 1990
SUBJECTS: Electrodynamics. Gravitation. Relativity. Symmetry. ISBN: 0201416255 (U.S.) : $33.95

Alexander, S.
Gravity and inertia : the mechanism / by S. Alexander. Santa Barbara, Calif. : G.E.C. Research, c1985. 64 p. : ill. ; 23 cm. LC CALL NUMBER: QC178 .A44 1985
SUBJECTS: Gravitation. Inertia (Mechanics) ISBN: 0939525054

Harrigan, Gregory Leo, 1919-
The great gravity myth / Gregory Leo Harrigan. 2nd ed., rev. and enl. Minneapolis : Shanty Press, 1991. p. cm. LC CALL NUMBER: QC178 .H28 1991 *CIP - NOT YET IN LC* SUBJECTS: Gravitation--Miscellanea. Serendipity in science. ISBN: 0916403033 (lib. bdg.) : $8.95

Soldano, B. A.
A new look at Maxwell's equations and the permittivity of free space / by B.A. Soldano. Greenville, S.C., U.S.A. : Grenridge Pub., 1982. 50 p. LC CALL NUMBER: QB341 .S65 1982
SUBJECTS: Gravitation. Maxwell equations.

Gallimore, J. G.
Transverse paraphysics : the new science of space, time, and gravity control J.G.

Gallimore. Millbrae, Calif. : Tesla Book Co., 1982. ix, 359 p. LC CALL NUMBER: QC173.59.S65 G35 1982
SUBJECTS: Space and time. Gravitation.

Mancini Ridolfini, Niccolo.
Elettricita e magnetismo; rotazione elettro-magnetica gravitazionale. Bologna, L. Cappelli, 1931. vii, 506 p. illus. 25 cm. LC CALL NUMBER: QC518 .M36
SUBJECTS: Electromagnetic theory. Space and time. Gravitation.

King, Moray B.
Tapping the zero-point energy / Moray B. King. Provo, UT : Paraclete Pub., c1989. iii, 169 p. : ill. ; 22 cm.
LC CALL NUMBER: QC178 .K5575 1989
SUBJECTS: Antigravity. Radiation. Electromagnetics. Force and energy. ISBN: 0962335606 : $9.95

The Large N expansion in quantum field theory and statistical physics : from spin systems to 2-dimensional gravity / editors, Edouard Brezin, Spenta R. Wadia. Singapore ; River Edge, NJ : World Scientific, c1993. xiv, 1130 p. LC CALL NUMBER: QC174.45 .L37 1993
SUBJECTS: Quantum field theory. String models. Gauge fields (Physics) ISBN: 9810204558

Magnetic susceptibility of superconductors and other spin systems / edited by Robert A. Hein, Thomas L. Francavilla, and Donald H. Liebenberg. New York : Plenum Press, c1991. xx, 606 p. : ill. ; 26 cm. LC CALL NUMBER: QC611.97.M34 M34 1991
SUBJECTS: Superconductors--Magnetic properties--Magnetic susceptibility United States. Office of Naval Research. Office of Naval Research Workshop on Magnetic Susceptibility of Superconductors and Other Spin Systems (1991 : Coolfont, W. Va.) "Proceedings of the Office of Naval Research Workshop on Magnetic Susceptibility of Superconductors and Other Spin Systems, held May 20-23, 1991, in Coolfont, Berkeley Springs, West Virginia"--T.p. verso. ISBN: 0306441977

Spin waves and magnetic excitations / volume editors, A.S. Borovik-Romanov, S.K. Sinha. Amsterdam ; New York : North-Holland ; New York, N.Y. : Sole distributors for the U.S.A. and Canada, Elsevier Science Pub. Co., 1988. LC CALL NUMBER: QC762 .S66 1988
SUBJECTS: Spin waves. Magnons. Dielectrics--Magnetic properties. Metals--Magnetic properties.
Modern problems in condensed matter sciences ; v. 22 ISBN: 0444870687 (v. 1)

Aono, Osamu, 1937-
Rotation of a magnetic field / Osamu Aono and Ryo Sugihara. Nagoya, Japan : Institute of Plasma Physics, Nagoya University, 1986. 6 p. ; 30 cm. LC CALL NUMBER: QC717.6 .N35 no. 792 (ALTERNATE CLASS QC754.2.M3)
SUBJECTS: Magnetic fields. Electrodynamics. Research report (Nagoya Daigaku. Purazumu Kenkyujo) ; IPPJ-792.

Handbook of electron spin resonance : data sources, computer technology, relaxation, and ENDOR / edited by Charles P. Poole, Jr. and Horacio A. Farach. New York : American Institute of Physics, c1994. x, 660 p. : ill. ; 25 cm. LC CALL NUMBER: QC762 .H32 1994
SUBJECTS: Electron paramagnetic resonance. Electron nuclear double resonance spectroscopy. Relaxation phenomena. ISBN: 1563960443 (acid-free)

Mims, W. B.
The linear electric field effect in paramagnetic resonance / W. B. Mims. Oxford : Clarendon Press, 1976. 339 p. : ill. ; 24 cm. LC CALL NUMBER: QC762 .M55
SUBJECTS: Electron paramagnetic resonance. Electric fields. ISBN: 0198519443 : L9.75

Morrison, Clyde A. (Clyde Arthur), 1926-
Angular momentum theory applied to interactions in solids / C.A. Morrison. Berlin ; New York : Springer-Verlag, c1988. 159 p. ; 25 cm. LC CALL NUMBER: QD475 .M68 1988
SUBJECTS: Crystal field theory. Angular momentum. ISBN: 0387189904 (U.S. : pbk.)
---------------------------- Mirman, R.

Massless representations of the Poincare Group : electromagnetism, gravitation, quantum mechanics, geometry / R. Mirman. Commack, N.Y. : Nova Science Publishers, 1995. p. cm.
LC CALL NUMBER: QC20.7.G76 M57 1995 *CIP - NOT YET IN LC* SUBJECTS: Representations of groups. Poincare series. Electromagnetism. Gravitation. Quantum theory. Geometry. Mathematical physics. ISBN: 1560722592

Antunez de Mayolo, Santiago, 1887-1967.
The neutral element base of matter and probable cause of gravitation / Santiago Antunez de Mayolo. Lima, Peru : Universidad Nacional Mayor de San Marcos, 1948. 36 p. : ill. ; 22 cm.
LC CALL NUMBER: MLCS 94/12050 (Q)
SUBJECTS: Nuclear physics. Matter--Constitution. Translation of "Work presented in Spanish to the IV. South American Chemistry Congress, Santiago, Chile, March 1948."

Ciufolini, Ignazio, 1951-
Gravitation and inertia / Ignazio Ciufolini and John Archibald Wheeler. Princeton, N.J. : Princeton University Press, c1995. xi, 498 p. LC CALL NUMBER: QC173.59.G44 C58 1995
SUBJECTS: Geometrodynamics. General relativity. Gravitation. Inertia. ISBN: 0691033234 (acid-free paper)

TITLE: Excalibur Briefing
AUTHOR: Thomas E. Bearden
COPYRIGHT DATE: 1980, 1988
PUBLISHER: Strawberry Hill Press/A Walnut Hill Book ISBN# 0-89407-060-6
PURCHASED FROM: Tesla Book Co. or Fry's INC. INQ. COMMENTS ....
According to the front and rear covers this book explains paranormal phenomena and the interaction of mind and matter. There are 4 chapters plus a glossary and bibliography. 332 pages, 42 photographs, and 40 illustrations. Chapter one is called... A Sampling of Specific Paranormal Phenomena. Some of the subjects in this chapter are...Remote Viewing The Moray Radiant Energy Device, Thought Photography, Pavlita's Psychotronic Generators, UFO's, Kirlian Photograpy, Psychic Surgery Chapter Two is called...A Theoretical Background for Understanding PT, UFO's and PSI Phenomena...Some of the subjects are.... Unexplained Mysteries of Physics, Two Slit Experiment, Radionics, Biofields and Maverick Worlds Chapter Three is called...New Military Applications of PSI Research Some of the subjects covered are...Background to Psychotronic Research in the U.S and the U.S.S.R., Radiation of the U.S. Embassy, Hyperspace Howitzer operation, Virtual States and Hyperspaces, Feynman diagrams The Neurophone, Soviet Woodpecker signals The last chapter covers Soviet Phase Conjugate Directed Energy Weapons (Weapons that use time reversed Electromagnetic Waves) The Glossary is about 30 pages long and is very useful.

Bearden, T. E. (Thomas E.), 1930-
Excalibur briefing / Thomas E. Bearden ; foreword by John White ; special drawings by Hal Crawford. San Francisco : Strawberry Hill Press, c1980. LC CALL NUMBER: BF1999 .B387 1980
SUBJECTS: Occultism. Unidentified flying objects. ISBN: 0894070150 (pbk.) : $8.95

TITLE: Magnetism:An Introductory Survey
AUTHOR: E.W. Lee
COPYRIGHT DATE: 1963,1970
PUBLISHER: Dover Publications Inc. New York ISBN# 0-486-24689-2
PURCHASED FROM: Lindsay Publications
COMMENTS ....
Paperback, 280 pages, Some photographs and Illustrations Some of subjects covered are....Atomic Theory of Matter, Earth's Magnetism History of Magnetism, Magnetism in Scientific Research, Paramagnetism and Diamagnetism
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TITLE: Tesla: The Lost Inventions
AUTHOR: George Trinkhaus

COPYRIGHT DATE: 1988
PUBLISHER: High Voltage Press
ISBN# N/A
PURCHASED FROM: Lindsay Publications
COMMENTS ....
Paper, 33 Pages, 42 Illustrations. Describes Tesla's lost inventions in plain, easy to understand English. According to the author, patents are hard to understand. In the illustrations he shows the patent number. Some of the inventions include... Disk Turbine Rotary Engine
Magnifying Transmitter
Transport
Free Energy Receiver

----------- TITLE: Tesla: Man out of Time
AUTHOR: Margaret Cheney
COPYRIGHT DATE: 1981
PUBLISHER: Laurel Book by Dell Publishing Co. ISBN# 0-440-39077-X
PURCHASED FROM: Tesla Book Co. or Lindsay Publications COMMENTS ....
Paperback 320 Pages, 8 Pages of Rare Photographs Good biography of Tesla. 30 Chapters plus Reference Notes. Chapter 29 deals with Tesla's papers and what may have happened to them after he died.

----------- TITLE: The Cosmic Conspiracy
AUTHOR: Stan Deyo
COPYRIGHT DATE: 1978
PUBLISHER: West Australian Texas Trading
ISBN# 0-908477-00-7
PURCHASED FROM: Tesla Book Co.
COMMENTS ....
Paperback 200 Pages. The book is divided into 3 sections with each section containing at least 6 chapters. Plus there are 7 Appendices. At the end of each section there is a Suggested reading list for that section. Section One deals with research into Electro- Gravitic Propulsion Tesla, Weather Warfare, Conspiracys. Section Two deals with Mysticism and Numerology, mystery schools, Illuminati Section Three deals with Religious Ideas In the appendices there are articles on Townsend Brown, Einstein's Relativity error, Michelson Morley experiment, Electo-Dynamic Propulsion, Practical Ion Craft. Very fascinating book. -----
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------ TITLE: The Philadelphia Experiment: Project Invisibilty AUTHOR: William L. Moore, Charles Berlitz COPYRIGHT DATE: 1979
PUBLISHER: Fawcett Crest New York
ISBN# 0-449-24280-3
PURCHASED FROM: Waldenbooks
COMMENTS ....
Paperback 288 pages.
Book on the alleged Navy experiment to make a ship invisible; to radar or optically or both. Supposedly the ship not only became invisible but dematerialized and rematerialized at a distant location, then re-materialized at the original location (Philadelphia Navy Yard). Plus there were severe side effects to the crew members. Some of the crew were said to have disappeared into another dimension. Some never to return. Chapter 9 (The Unexpected Key) is very interesting because it describes an interview with a scientist who was involved with the Philadelphia experiment when it was being planned.

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The best introduction to dyads and dyadic analysis in electromagnetism in my opinion is the following book:

Hollis C Chen, Theory of Electromagnetic Waves: A Coordinate-Free Approach (1983, McGraw-Hill; 1992, TechBooks). ---------------
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It's already a proven fact that angular momentum will generate an opposing force to gravity in the way you describe. This is a purely General Relativistic effect. There's an article in the 1988 Foundations of Physics "An Exact Solution to Einstein's Field Equations: Gravitational Force Can Also Be Repulsive!"

It requires an immensely huge angular momentum to get any decent repulsion, such that you're not going to get it by any mechanical means
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For those of you who are not familiar with the obscure aspects of General Relativity, hopefully this will steer you in the right direction for further research and knowledge. Non-Newtonian gravitational fields, which may be either attractive or repulsive, can be generated from three effects. These are that of rotating masses, moving masses, or fluctuating masses relative to a stationary, non-rotating body. These effects are similar to centrifugal, Coriolis, and other inertial forces and were first described by W. de Sitter in 1916 and Hans Thirring in 1918. Dr. Robert L. Forward published his Guidelines to Antigravity in March 1963 in the American Journal of Physics. Dr. Forward is an expert in General Relativity and Gravity Research and studied under Weber at the University of Maryland. In his guidelines article, he discusses the dipole effect of gravity as predicted by General Relativity. Unfortunately, the forces generated are extremely weak without very dense mass or extremely high angular velocities. I suggest that everyone with an interest in such aspects obtain a copy of this article and read it through before passing any judgements as to these forces existing or being generated!
-- Phillip Carpenter

Might a mass (gravitational charge) in motion also produce another type of field much like a magnetic one?
Something like this is "gravitomagnetic effect" is theoretically predicted. If you were in such a field, it would simply give the impression that you were in a locally rotating frame of reference, so moving objects would experience coriolis forces, even when you were not rotating relative to distant reference points. As the effect is of the order of v1 v2/c^2 where v1 is the speed of the gravitational source and v2 is the speed of the test object, it is extremely small and has not yet been measured.
Note also that a rotating massive object is expected to give rise to a similar field in the same way as a current loop gives rise to a magnetic field. This is known as the Lense-Thirring effect. A first-order Special Relativity approximation (which only applies for a locally inertial frame of reference where space isn't significantly curved) is simply that the rotation field is (v1 x g)/c^2 where g is the Newtonian acceleration vector v1 is the velocity of the source object. The acceleration that field generates for a body moving with velocity v2 is v2 x (v1 x g)/c^2. Note for comparison that the magnetic field is B = (v1 x E)/c^2 so the magnetic force is q v2 x (v1 x E)/c^2. The gravitational rotation field calculated in this way is equal to 2w where w is the apparent angular velocity of rotation. It is hoped that "conscience-
guided" satellite experiments may confirm this effect within a few years, but at present there are too many other disturbances which make it too difficult to measure such a small effect. The rotation field, whether caused by a linearly moving mass or a rotating object, only affects moving masses. However, there is of course a much stronger associated acceleration field which affects all masses. From the subjective point of view, the acceleration field may appear to be partly linear acceleration and partly "centrifugal" force associated with rotary motion, but this is a higher-order effect.
-- Jonathan Scott

Some scientists in Boulder, CO (USA) have suceeded in cooling down matter into the elusive Bose-Einstein condensate. The kinetic energy of the atoms in this state have been removed. If you could maintain this state in stable form and spin it, the angular momentum would repel the earth and lift many times its own mass. Outside of the atmosphere, this could produce the desired gravitational dipole effect. --
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Bonaldi, M., et al., "Inertial and Gravitational Experiments With Superfluids: A Progress Report," Proceedings of the Fourth Marcel Grossmann Meeting on General Relativity, Elsevler Science Publishers B.V., 1985, pp. 1309-1317.

Title: ANGULAR MOMENTUM PARADOXES WITH SOLENOIDS AND MONOPOLES In: Phys.Lett.118B:385,1982
Date/Source: August 1982
Fermilab Library: FERMILAB-PUB-82/53-THY -- Preprint -- Available

Title: Long range effects in asymptotic fields and angular momentum of classical field electrodynamics Date/Source: February 1995
Fermilab Library: CALL NUMBER DESY-95-035 -- Preprint -- Available

Title: Angular Momentum
Authors: Brink, D. M. (David Maurice), and G.R. Satchler Date/Source: Oxford : Clarendon Press ; New York : Oxford University Press, 1993.
Fermilab Library: CALL NUMBER QC793.3.A5 B75 1993 -- Book -- Available -------
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AUTHOR(s): Hayasaka, Hideo Takeuchi, Sakae
TITLE: Gravitation and Astrophysics.
Summary: Anomalous weight reduction on a gyroscope's right rotations
around the vertical axis on the Earth.
In: Physical review letters.
DEC 18 1989 v 63 n 25 Page 2701

AUTHOR(s): Starzhinskii, V.M.
TITLE: An exceptional case of motion of the Kovalevskaia
gyroscope.
In: PMM, Journal of applied mathematics and mechanic 1983 v 47 n 1 Page 134

From: sphinx@world.std.com (John Sangster, SPHINX Technologies) Subject: Weight Reduction in Spinning Masses Date: Fri, 3 Nov 1995 06:04:35 GMT

Recently Hideo Hayasaka and Sakae Takeuchi of the Engineering Faculty at Tohoku University in Japan have published an experimental result of this sort. They found that gyroscopes spinning clockwise as seen from above, at their location, exhibited a decrease in relative mass of 5.07 x 10^-5 and 4.22 x 10^-5 respectively for the two gyroscope configurations studied. (Weight was multiplied by 1-e where e is the relative factors given above, if I haven't botched up in my arithmetic.) The effect as plotted in the paper I saw appears to be perfectly linear to within reasonable experimental error, thus giving a rotational velocity at which the weight would go to zero which I made out to be 3.27 MHz (million rotations per second) in the first case and 3.95 MHz in the second.
That was with CLOCKWISE rotation as seen from above. With COUNTERclockwise rotation, the same experimental setup showed ZERO EFFECT. Zip. Nada. Nichts. Nyechevo. You get the idea. For one thing, this result makes it almost certain that they are NOT dealing with bad lab technique. Not to mention the fact that they spent nearly a year and a half going over and over their setup and trying to answer all objections by the reviewers of their Physical Review Letters paper (it eventually appeared in PRL (63 2701)). As far as I know, nobody has published a theoretical model that accounts for these observations. The idea of a physical phenomenon that appears only in one direction of rotation is rather unprecedented. I know of only one other mathematical/physical phenomenon that does this, and I'm trying to understand how the two might be related, but without success as yet.
-- John Sangster

Physicist Alex Harvey wrote an article about the Hayakawa-Taguechi experiment. The article was published in:

Nature, Aug 23 1990, Vol 346 Page 705

You'll also find other references there. Harvey shows mathematically that an angular momentum vector aligned antiparallel to the local gravitational field violates the equivalence principle. He also shows that the path of a spinning body under gravity need not be geodesic. Here are two "holes" in GR that seem to account for the behavior of H & T's

gyros. New experiments should be designed to force the asymmetry to appear, as predicted by theory, rather than passively leave the results to chance.
There is a dimensional error of Hayasaka and Takeuchi which CAN be corrected by supplying a quantity that restores proper dimensionality. In simplest terms, H and T's result looks like: { deltaN = - (proportionality constant) m w r } where deltaN is the weight change in Newtons, m is the mass of the rotor in kg, w is the rotation frequency in angular units and r is the radius of the rotor in meters. The units of the missing quantity are radians per second. The rotation, w, has already been counted. The missing quantity is the precession, Wp. With clockwise rotation, the vector J points down the spin axis, while the precession vector, Wp, points up the spin axis.
Physicist Alex Harvey, writing about H and T's results, confirmed that there is no (symmetrical) weight gain, no effect at all, with counter-clockwise rotation, J (up). In this case, says Harvey, "[J] is parallel to the gravitational field."
-- laradex3@sj.znet.com

AUTHOR(s): Harvey, Alex
TITLE(s): Complex Transformation of the Kasner Metric.
In: General relativity and gravitation.
OCT 01 1989 v 21 n 10 Page 1021

AUTHOR(s): Harvey, Alex
TITLE(s): Cosmological models.
In: American journal of physics.
OCT 01 1993 v 61 n 10 Page 901

AUTHOR(s): Harvey, Alex
TITLE(s): Identities of the scalars of the four-dimensional
Riemannian manifold.
In: Journal of mathematical physics.
JAN 01 1995 v 36 n 1 Page 356

AUTHOR(s): Harvey, Alex
TITLE(s): Will the Real Kasner Metric Please Stand Up.
In: General relativity and gravitation.
DEC 01 1990 v 22 n 12 Page 1433

>Maybe I've missed it, but I've looked seriously, and there seems to be no information in undergraduate or graduate level physics reference books which mentions the relationship between macroscopic and microscopic angular momentum -- much less provides any analysis or explanation linking quantum angular momentum to macroscopic angular momentum.

You're catching on. The subject of compound angular momentum, or internal and external angular momentum, or intrinsic and extrinsic angular momentum has been a repressed subject for about 2 and half decades. Add to that list, spherical pendulums, Coriolis effect, except as applied to balistics and meteorology as used by the US military, and Shafer's pendulum, that neat little device used as the artifical horizon of aircraft.

>How does quantum angular momentum become organized from a microscopic to a macroscopic level? Has anyone ever published any work about this? I can't find any.

There isn't any that I know of, though back in the late fifties, there was a fellow named Edward Condon at the University of Colorado who was fairly proficient on the subject. So much so that he wrote the rotational dynamics section, called noninertial dynamics at the time, of the reference "The Handbook of Physics" which he also co-edited (Chapter 5). I don't recall offhand who the publisher was (Harcourt/Brace?), though it was endorsed by the American Institute of Physics. Later, when Mr Condon was the head of the USAF project 'Blue Book', he labored to supress his own work when the directive was handed down from the Navy's Turtle Island project.
-- James Youlton

In the Barnett effect a long iron cylinder, when rotated at high speed about its longitudinal axis, is found to develop a measurable component of magnetization, the value of which is proportional to the angular speed. The effect is attributed to the influence of the

impressed rotation upon the revolving electronics systems due to the mass property of the unpaired electrons within the atoms. -- Henry Wallace
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Barnett, S.J., "Magnetization By Rotation," The American Physical Society, Second Series, vol. VI, No. 2, Jun., 1915, pp. 171-172.

Barnett, S.J., "Magnetization By Rotation," The Physical Review, Second Series, vol. VI., No. 4, Oct., 1915, pp. 239-270. ----------------------------
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The Barnett Effect is known to me as the effect of a change in volume of a magnetic material in response to a change in it's magnetization strength. If a ferrite material is exposed to a higher magnetization field (more current through the coil) the ferritd will change in volume. I was not aware that this has anything to do with alignment to a spinning axis. For further information about this aspect of the Barnett effect, see: Ref. Handbook of Magnetic Phenomena, by Harry S Burk, Van Nostrand Reinhold 1986 Page 262. -- William Clymer
----

Magnetic systems with competing interactions : frustrated spin systems / edited by H.T. Diep. Singapore ; River Edge, N.J. : World Scientific, c1994. xiv, 335 p. : ill. ; 24 cm.
LC CALL NUMBER: QC754.2.S75 M34 1994
SUBJECTS: Magnetization. Rotational motion. Spin waves. Ferromagnetism.
CONTENTS:
Nonlinear phenomena and chaos in magnetic materials / P.E. Wigen -- Some nonlinear effects in magnetically ordered materials / H. Suhl -- Spin-wave instability processes in ferrites / M. Chen & C.E. Patton -- Spin-wave dynamics in a ferrimagnetic sphere: experiments and models / P.H. Bryant, D.C. Jeffries, & K. Nakamura -- Spin-wave auto-oscillations in YIG spheres driven by parallel pumping and subsidiary resonance / S.M. Rezende & A. Azevedo -- Strong chaos in magnetic resonance / M. Warden -- Magnetostatic modes in thin films / R.D. McMichael & P.E. Wigen -- Fractal properties in magnetic crystal / H. Yamazaki -- Spin-wave envelope solitons in magnetic films / A.N. Slavin, B.A. Kalinikos, & N.G. Korshikov. ISBN: 9810210051

Hence the Wilson-Blackett proportionality between the angular momentum of planets, stars etc and their magnetic moment. For more information see Science News Aug 6 '94 p82. -
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AUTHOR(s): Bloxham, Jeremy Gubbins, David
TITLE(s): The Evolution of the Earth's Magnetic Field.
Summary: The origin of the field has fascinated more than a dozen
generations of physicists. Molten iron in the outer core, driven by convection and influenced by the earth's rotation, acts as a dynamo that generates the field. Now historical records of magnetic-field changes yield new insights into the process and into how the field may behave in the future.
In: Scientific American. DEC 01 1989 v 261 n 6 Page 68

AUTHOR(s): Malov, I.F.
TITLE(s): Angle between the magnetic field and the rotation axis in
pulsars.
In: Soviet astronomy.
MAR 01 1990 v 34 n 2 Page 189

AUTHOR(s): Marsheva, N. M.
TITLE(s): Permanent rotation of a heavy rigid body in a magnetic
field.
In: Moscow university mechanics bulletin. 1989 v 44 n 1

AUTHOR(s): Vitale, S. Bonaldi, M. Falferi, P.
TITLE: Magnetization by rotation and gyromagnetic gyroscopes.

Summary: We discuss how the general phenomenon of magnetization by
rotation may be used probe the angular velocity of the laboratory with respect to a local frame of inertia. We show that gyroscope with no moving parts based on this pheno-
In: Physical review B: Condensed matter. JUN 01 1989 v 39 n 16 p B Page 11993

CONDENSED MATTER THEORY, ABSTRACT COND-MAT/9509141 From: Erwin Frey Date: Fri, 22 Sep 1995 09:43:52 +0200
Critical Dynamics of Magnets
Authors: Erwin Frey , Franz Schwabl (TU Muenchen) Comments: Review article (154 pages, figures included) We review our current understanding of the critical dynamics of magnets above and below the transition temperature with focus on the effects due to the dipole--dipole interaction present in all real magnets. Significant progress in our understanding of real ferromagnets in the vicinity of the critical point has been made in the last decade through improved experimental techniques and theoretical advances in taking into account realistic spin-spin interactions. We start our review with a discussion of the theoretical results for the critical dynamics based on recent renormalization group, mode coupling and spin wave theories. A detailed comparison is made of the theory with experimental results obtained by different measuring techniques, such as neutron scattering, hyperfine interaction, muon--spin--resonance, electron--
spin--resonance, and magnetic relaxation, in various materials. Furthermore we discuss the effects of dipolar interaction on the critical dynamics of three--
dimensional isotropic antiferromagnets and uniaxial ferromagnets. Special attention is also paid to a discussion of the consequences of dipolar anisotropies on the existence of magnetic order and the spin--wave spectrum in two--dimensional ferromagnets and antiferromagnets. We close our review with a formulation of critical dynamics in terms of nonlinear Langevin equations.

Paper: cond-mat/9501029
From: Kazuhiro Kuboki Date: Mon, 09 Jan 1995 10:40:11 EST
Title: Proximity-induced time-reversal symmetry breaking at Josephson junctions between unconventional superconductors
Author: Kazuhiro Kuboki and Manfred Sigrist
We argue that a locally time-reversal symmetry breaking state can occur at Josephson junctions between unconventional superconductors. Order parameters induced by the proximity effect can combine with the bulk order parameter to form such a state. This property is specifically due to the intrinsic phase structure of the pairing wave function in unconventional superconductors. Experimental consequences of this effect in high-temperature superconductors are examined.

Paper: cond-mat/9501088
From: David Benedict Bailey Date: Thu, 19 Jan 1995 11:34:10 -0800 (PST) Title: Gapless Time-Reversal Symmetry Breaking Superconductivity Authors: A. M. Tikofsky and D. B. Bailey We consider a layered superconductor with a complex order parameter whose phase switches sign from one layer to the next. This system is shown to exhibit gapless superconductivity for sufficiently large interlayer pairing or interlayer hopping. In addition, this description is consistent with experiments finding signals of time-reversal symmetry breaking in high-
temperature superconductors only at the surface and not in the sample bulk.

Paper: cond-mat/9501133
From: ioffe@physics.rutgers.edu (Lev Ioffe) Date: Mon, 30 Jan 95 08:59:22 EST
Title: On the spin density wave transition in a two dimensional spin liquid.
Authors: B. L. Altshuler, L. B. Ioffe, A. I. Larkin, A. J. Millis. Strongly correlated two dimensional electrons are believed to form a spin liquid in some regimes of density and temperature. As the density is varied, one expects a transition from this spin liquid state to a spin density wave antiferromagnetic state. In this paper we show that it is self-consistent to assume that this transition is second order

and, on this assumption, determine the critical behavior of the 2p_F susceptibility, the NMR rates T1 and T2 and the uniform susceptibility. We compare our results to data on high Tc materials.

Paper: gr-qc/9502041
From: Barry Haddow Date: Fri, 24 Feb 1995 18:59:15 (GMT)
Title: Purely Magnetic Spacetimes
Author: Barry Haddow (Trinity College, Dublin, Ireland) Purely magnetic spacetimes, in which the Riemann tensor satisfies R_{abcd}u^bu^d=0 for some unit timelike vector u^a, are studied. The algebraic consequences for the Weyl and Ricci tensors are examined in detail and consideration given to the uniqueness of u^a. Some remarks concerning the nature of the congruence associated with u^a are made.

Paper: cond-mat/9502103
From: deb@rri.ernet.in (Debnarayan Jana) Date: Fri, 24 Feb 95 11:23:21+050
Title: Universal Diamagnetism of Charged Scalar Fields Authors: Debnarayan Jana
We show that charged scalar fields are always diamagnetic, even in the presence of interactions and at finite temperatures. This generalises earlier work on the diamagnetism of charged spinless bosons to the case of infinite degrees of freedom.

"CP Violation and Antigravity Revisited", G. Chardin, Nuclear Physics, Jun 7 1993, Vol 558

"Equivalence Principal Violation, Antigravity and Anyons Induced by Gravitational Chern-Simons Couplings", S. Deser, Classical and Quantum Gravity, 1992, Vol 9 Supp

"The Arguments Against Antigravity and the Gravitational Acceleration of Anti-Matter", Michael Martin, Physics Reports, Jul 1 1991, Vol 205

"Empirical Limits to Antigravity", Ericson & Richter, Europhysics Letters, Feb 15 1990, Vol 11 no 4

"Chern-Simons Quantizations of (2+1) Anti-de Sitter Gravity on a Torus", K. Ezawa, Classical and Quantum Gravity, Feb 1 1995 Vol 12 No 2

"Green's Function for Anti-de Sitter Space Gravity", Gary Kleppe, Physical Review d: Particles, Fields, Gravity; Dec 15 1994 Vol 50 No 12

"Lowest Eigenvalues of the Energy Operator for Totally Anti Symmetric Massless Fields of the N-Dimensional Anti-de Sitter Group", R.R. Metsaev, Classical and Quantum Gravity, Nov 1 1994, Vol 11 No 11

"The Positivity of Energy for Asymptotically Anti-de Sitter Spacetimes", E. Woolgar, Classical and Quantum Gravity, Jul 1 1994, Vol 11 No 7

"Vacuum Polarization Near Asymptotically Anti-de Sitter Black Holes in Odd Dimensions", Shiraishi & Maki, Classical and Quantum Gravity, Jul 1 1994, Vol 11 No 7

"Strong Anti Gravity: Life in the Shock Wave", Fabbrichesi & Roland, Nuclear Physics B, Dec 21 1992, Vol 388 No 2

"Global Solutions of Yang-Mills Equations on Anti-de Sitter Spacetime", Choquet-Bruhat, Classical and Quantum Gravity, Dec 1 1989, Vol 6 No 12

"The Scalar Wave Equation on Static de Sitter and Anti-de Sitter Spacetimes", D. Polarski, Classical and Quantum Gravity, Jun 1 1989

"Lehman Representation of the Spinor Two-Point Function in Anti-de Sitter Space", E. Gath, Classical and Quantum Gravity, May 1 1989, Vol 6 no 5

Dr. Bernhard Haisch has modeled inertial mass as deriving from an accelerated body's interaction with the zero point field (ZPF), consonant with a large body of refereed physics literature.

Haisch in Feb 1994 Phys. Rev. A
Science vol 263 p 612
Scientific American vol 270, p 30
New Scientist 25 Feb 1995 p 30

"Gravity as a Zero-Point-Fluctuation Force," H.E. Puthoff, Physical Review A: General Physics. Mar 1 1989, Vol39 No 5 ---------------------------
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The 4 February 1994 issue of Science magazine has an article about a new theory of inertia. A recent paper by Bernhard Haisch, Alfonso Rueda and Hal Puthoff in the 1 Feb 1994 issue of Physical Review A, based on earlier work by Andrei Sakharov, derives inertia from quantum electromagnetic vacuum fluctuations. The idea is that if inertia is due to some strange quantum EM effects, it might be understood and controlled, and even neutralized. Haisch is at the Lockheed Palo Alto laboratories, Rueda, at Cal. State. Long Beach, and Puthoff at the Institute for Advanced Studies in Austin Texas. Needless to say, this new theory is serious, but very controversial physics. A test is planned later this year at the SLAC linear accelerator by exposing a high energy electron beam to terawatt laser. Keep tuned!
-- John H. Chalmers Jr

A recent controversial theory of Austin Institute for Advanced Study physicist Hal Puthoff and his collaborators Haisch and Rueda appears to explain gravity as not an intrinsic property of matter but as an indirect consequence of Maxwellian electromagnetic radiation, namely that (as earlier suggested by the late Russian dissenter Sakharov) gravity is a "shadow effect" similar to the Casimir Effect of quantum electrodynamics. Bass points out that if the Haisch-Puthoff-Rueda theory is correct then Hodowanec's idea of tapping the earth's gravity field in some electromagnetic way not hitherto suggested is conceivable. - Joel McClain
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Puthoff and his collaborators have gone so far as to use SED (Stochastic Electro-Dynamics) to _explain_ both gravitational & inertial mass and to show their equivalence, and to derive Newton's F = Ma, and to derive Mach's principle (without which Einstein admitted that no theory of gravity could claim to be complete), and to derive Dirac's "cosmological numerical coincidences" as inevitabilities, and to derive Newtonian gravity, and to derive the Newton-Cavendish parameter G!!! -- Robert Bass
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It is an amazing coincidence that the total Newtonian gravitational potential energy of any object due to all masses in the universe is equal in magnitude to its total energy, at least to within a small factor, considering that this involves an expression involving multiple factors of the order of 10 to the 40th power. This was pointed out by Dirac in his Large Numbers Hypothesis, and used as part of a beautiful illustrative theory by Dennis Sciama [1], in which he constructs a theory of gravity closely analogous to the classical theory of electromagnetism, and shows that inertia can be directly attributed to the gravitational effect of accelerating relative to the gravitational potential sources of the whole universe (or indeed of accelerating the whole universe relative to the object, because in Sciama's theory, the two points of view are equivalent). This theory is obviously consistent with Mach's Principle (which is effectively that inertial motion is in some sense relative to the rest of universe). Sciama's theory is only a simplified approximation, but it is so neat that it seems likely that some similar principle must apply also within General Relativity. However, one of its most basic implications is that the gravitational "constant" G would depend on the distribution of matter in the universe, which seems to be in direct conflict with GR. I personally think GR is probably not quite right. -- Jonathan Scott

[1] D.W.Sciama, "On the Origin of Inertia", M.N.R.A.S. Vol. 113, p34, 1953.

GENERAL RELATIVITY & QUANTUM COSMOLOGY, ABSTRACT GR-QC/9412012 From: "Haret Rosu" Date: 3 Dec 94 19:36:00 CST
Classical and quantum inertia: a heuristic introduction, Author(s): Haret C. Rosu
Report: IFUG-27/94,
Comments: 20 pages, LaTex 11pt, no figures. A non-technical discussion of the problem of inertia is provided both in classical physics and in the quantum world. After briefly reviewing the classical formulations (WEP, EEP, and SEP), I pass to a presentation of the equivalence statements for quantum vacuum states. One can also find a number of related comments and suggestions.

Krech, Michael.
The Casimir effect in critical systems / Michael Krech. Singapore ; River Edge, NJ : World Scientific, c1994. x, 253 p. : ill. ; 23 cm. LC CALL NUMBER: QC173.4.C74 K74 1994 SUBJECTS: Critical phenomena. Casimir effect. ISBN: 9810218451

Cavity quantum electrodynamics/edited by Paul R. Berman. Boston : Academic Press, c1994. xvi, 464 p. : ill. ; 24 cm. LC CALL NUMBER: QC446.2 .C38 1994
SUBJECTS: Quantum optics. Quantum electrodynamics. Casimir effect. ISBN: 0120922452 (alk. paper)

Long-range Casimir forces : theory and recent experiments on atomic systems Edited by Frank S. Levin and David A. Micha. New York : Plenum Press, c1993. LC CALL NUMBER: QC680 .L63 1993
SUBJECTS: Casimir effect.
ISBN: 0306443856

Physics in the making : essays on developments in 20th century physics: in honour of H.B.G. Casimir on the occasion of his 80th birthday/ edited by A. Sarlemijn and M.J. Sparnaay. Amsterdam : North-Holland; New York, N.Y., U.S.A. : Sole distributors for the U.S.A. and Canada, Elsevier Science Pub. Co., 1989. xiv, 361 p. : ill. ; 23 cm. LC CALL NUMBER: QC7 .P48 1989
SUBJECTS: Casimir, H. B. G. (Hendrik Brugt Gerhard), 1909- Casimir, H. B. G. (Hendrik Brugt Gerhard), 1909- Sarlemijn, Andries, 1936-
Sparnaay, M. J. (Marcus Johannes)
ISBN: 0444881212

Edwards-Casimir Quantum Vacuum Drive --
A hypothetical drive exploiting the peculiarities of quantum mechanics by restricting allowed wavelengths of virtual photons on one side of the drive (the bow of the ship); the pressure generated from the unrestricted virtual photons toward the aft generates a net force and propels the drive. ----
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CONDENSED MATTER, ABSTRACT COND-MAT/9505108 From: moraes@guinness.ias.edu (Fernando Moraes) Date: Tue, 23 May 95 17:12:35 EDT
Enhancement of the magnetic moment of the electron due to a topological defect
Author(s): Fernando Moraes (Institute for Advanced Study, Princeton) In the framework of the theory of defects/three-dimensional gravitation, it is obtained a positive correction to the magnetic moment of the electron bound to a disclination in a dielectric solid. With the disclination modelled as a parallel plate casimir effect.

HIGH ENERGY PHYSICS - THEORY, ABSTRACT HEP-TH/9212077 From: milton@phyast.nhn.uoknor.edu (Kim Milton) Date: Fri, 11 Dec 92 16:13:13 CST
MAXWELL-CHERN-SIMONS CASIMIR EFFECT, KIMBALL A. MILTON, DEPARTMENT OF PHYSICS AND ASTRONOMY, UNIVERSITY OF OKLAHOMA In odd-dimensional spaces, gauge invariance permits a Chern-Simons mass term for the gauge fields in addition to the usual Maxwell-Yang-Mills kinetic energy term. We study the Casimir effect in such a (2+1)-dimensional Abelian theory. For the case of parallel conducting lines the result is the same as for a scalar field. For the case of

circular boundary conditions the results are completely different, with even the sign of the effect being opposite for Maxwell-Chern-Simons fields and scalar fields. We further examine the effect of finite temperature. The Casimir stress is found to be attractive at both low and high temperature. Possibilities of observing this effect in the laboratory are discussed.

GENERAL RELATIVITY & QUANTUM COSMOLOGY, ABSTRACT GR-QC/9303038 PHYS. REV. D 48, 776 (1993)
FROM: LFORD@PEARL.TUFTS.EDU
Date: Wed, 31 Mar 1993 17:47 EDT
MOTION OF INERTIAL OBSERVERS THROUGH NEGATIVE ENERGY, BY L.H. FORD AND THOMAS A. ROMAN,
Recent research has indicated that negative energy fluxes due to quantum coherence effects obey uncertainty principle-type inequalities of the form $|\Delta E|\,{\Delta \tau} \lprox 1\,$. Here $|\Delta E|$ is the magnitude of the negative energy which is transmitted on a timescale $\Delta \tau$. Our main focus in this paper is on negative energy fluxes which are produced by the motion of observers through static negative energy regions. We find that although a quantum inequality appears to be satisfied for radially moving geodesic observers in two and four-dimensional black hole spacetimes, an observer orbiting close to a black hole will see a constant negative energy flux. In addition, we show that inertial observers moving slowly through the Casimir vacuum can achieve arbitrarily large violations of the inequality. It seems likely that, in general, these types of negative energy fluxes are not constrained by inequalities on the magnitude and duration of the flux. We construct a model of a non-gravitational stress-energy detector, which is rapidly switched on and off, and discuss the strengths and weaknesses of such a detector.

GENERAL RELATIVITY & QUANTUM COSMOLOGY, ABSTRACT GR-QC/9304008 PHYS. REV. D 47, 4510 (1993).
FROM: LFORD@PEARL.TUFTS.EDU
Date: Tue, 6 Apr 1993 12:56 EDT
SEMICLASSICAL GRAVITY THEORY AND QUANTUM FLUCTUATIONS, BY CHUNG-I KUO AND L. H. FORD.
We discuss the limits of validity of the semiclassical theory of gravity in which a classical metric is coupled to the expectation value of the stress tensor. It is argued that this theory is a good approximation only when the fluctuations in the stress tensor are small. We calculate a dimensionless measure of these fluctuations for a scalar field on a flat background in particular cases, including squeezed states and the Casimir vacuum state. It is found that the fluctuations are small for states which are close to a coherent state, which describes classical behavior, but tend to be large otherwise. We find in all cases studied that the energy density fluctuations are large whenever the local energy density is negative. This is taken to mean that the gravitational field of a system with negative energy density, such as the Casimir vacuum, is not described by a fixed classical metric but is undergoing large metric fluctuations. We propose an operational scheme by which one can describe a fluctuating gravitational field in terms of the statistical behavior of test particles. For this purpose we obtain an equation of the form of the Langevin equation used to describe Brownian motion.

HIGH ENERGY PHYSICS - PHENOMENOLOGY, ABSTRACT HEP-PH/9307258 From: langfeld@ptsun1.tphys.physik.uni-tuebingen.de (Kurt Langfeld) Date: Tue, 13 Jul 93 08:04:30 +0200
CASIMIR EFFECT OF STRONGLY INTERACTING SCALAR FIELDS, BY K. LANGFELD, F. SCHMUSER, AND H. REINHARDT
Non-trivial $\phi ^{4}$-theory is studied in a renormalisation group invariant approach inside a box consisting of rectangular plates and where the scalar modes satisfy periodic boundary conditions at the plates. It is found that the Casimir energy exponentially approaches the infinite volume limit, the decay rate given by the scalar condensate. It therefore essentially differs from the power law of a free theory. This might provide experimental

access to properties of the non-trivial vacuum. At small interplate distances the system can no longer tolerate a scalar condensate, and a first order phase transition to the perturbative phase occurs. The dependence of the vacuum energy density and the scalar condensate on the box dimensions are presented.

GENERAL RELATIVITY & QUANTUM COSMOLOGY, ABSTRACT GR-QC 9310007 PHYSICA SCRIPTA 48, 649 (1993)
FROM: harald@nordita.dk (Harald H. Soleng)
Date: Mon, 4 Oct 93
INVERSE SQUARE LAW OF GRAVITATION IN (2+1)-DIMENSIONAL SPACE-TIME AS A CONSEQUENCE OF CASIMIR ENERGY, H. H. SOLENG, The gravitational effect of vacuum polarization in space exterior to a particle in (2+1)-dimensional Einstein theory is investigated. In the weak field limit this gravitational field corresponds to an inverse square law of gravitational attraction, even though the gravitational mass of the quantum vacuum is negative. The paradox is resolved by considering a particle of finite extension and taking into account the vacuum polarization in its interior.

HIGH ENERGY PHYSICS - THEORY, ABSTRACT HEP-TH/9312069 From: segui@cc.unizar.es
Date: Thu, 9 DEC 93 13:50 GMT
A MODIFIED SCHWINGER'S FORMULA FOR THE CASIMIR EFFECT, M.V. COUGO-PINTO, C. FARINA AND ANTONIO J. SEGUI-SANTONJA
After briefly reviewing how the (proper-time) Schwinger's formula works for computing the Casimir energy in the case of "scalar electrodynamics" where the boundary conditions are dictated by two perfectly conducting parallel plates with separation "a" in the Z-axis, we propose a slightly modification in the previous approach based on an analytical continuation method. As we will see, for the case at hand our formula does not need the use of Poisson summation to get a (renormalized) finite result.

HIGH ENERGY PHYSICS - THEORY, ABSTRACT HEP-TH/9401123 From: segui@cc.unizar.es
Date: Tue, 25 JAN 94 21:47 GMT
SCHWINGER'S METHOD FOR THE MASSIVE CASIMIR EFFECT, BY M.V. COUGO-PINTO, C. FARINA AND A.J. SEGUI-SANTONJA
We apply to the massive scalar field a method recently proposed by Schwinger to calculate the Casimir effect. The method is applied with two different regularization schemes: the Schwinger original one by means of Poisson formula and another one by means of analytical continuation.

HIGH ENERGY PHYSICS - THEORY, ABSTRACT HEP-TH/9405060 From: Shtykov Nikolay Date: Tue, 10 May 94 17:40:50 JST
THE FINITE VACUUM ENERGY FOR SPINOR, SCALAR AND VECTOR FIELDS, N.SHTYKOV We compute the one-loop potential (the Casimir energy) for scalar, spinor and vectors fields on the spaces $\,R^{m+1}\, \times\,Y$ with $\,Y=\,S^N\,,CP^2$. As a physical model we consider spinor electrodynamics on four-dimensional product manifolds. We examine the cancelation of a divergent part of the Casimir energy on even-dimensional spaces by means of including the parameter $\,M$ in original action. For some models we compare our results with those found in the literature.

HIGH ENERGY PHYSICS - THEORY, ABSTRACT HEP-TH/9408172 From: LFORD@PEARL.TUFTS.EDU
Date: Tue, 30 Aug 1994 16:45:05 -0400 (EDT)
DECOHERENCE AND VACUUM FLUCTUATIONS, L.H. FORD, TUFTS UNIVERSITY The interference pattern of coherent electrons is effected by coupling to the quantized electromagnetic field. The amplitudes of the interference maxima are changed by a factor which depends upon a double line integral of the photon two-point function around the closed path of the electrons. The interference pattern is sensitive to shifts in the vacuum fluctuations in regions from which the electrons are excluded. Thus

this effect combines aspects of both the Casimir and the Aharonov-Bohm effects. The coupling to the quantized electromagnetic field tends to decrease the amplitude of the interference oscillations, and hence is a form of decoherence. The contributions due to photon emission and to vacuum fluctuations may be separately identified. It is to be expected that photon emission leads to decoherence, as it can reveal which path an electron takes. It is less obvious that vacuum fluctuations also can cause decoherence. What is directly observable is a shift in the fluctuations due, for example, to the presence of a conducting plate. In the case of electrons moving parallel to conducting boundaries, the dominant decohering influence is that of the vacuum fluctuations. The shift in the interference amplitudes can be of the order of a few percent, so experimental verification of this effect may be possible. The possibility of using this effect to probe the interior of matter, e.g., to determine the electrical conductivity of a rod by means of electrons encircling it is discussed. (Presented at the Conference on Fundamental Problems in Quantum Theory, University of Maryland, Baltimore County, June 18-22, 1994.)

GENERAL RELATIVITY & QUANTUM COSMOLOGY, ABSTRACT GR-QC/9410043 PHYS. REV. D 51, 4277(1995).
FROM: FORD@TUHEP.PHY.TUFTS.EDU
Date: Fri, 28 Oct 1994 20:33 EST
AVERAGED ENERGY CONDITIONS AND QUANTUM INEQUALITIES, L.H. FORD AND THOMAS A. ROMAN
Connections are uncovered between the averaged weak (AWEC) and averaged null (ANEC) energy conditions, and quantum inequality restrictions on negative energy for free massless scalar fields. In a two-dimensional compactified Minkowski universe, we derive a covariant quantum inequality-type bound on the difference of the expectation values of the energy density in an arbitrary quantum state and in the Casimir vacuum state. From this bound, it is shown that the difference of expectation values also obeys AWEC and ANEC-type integral conditions. In contrast, it is well-known that the stress tensor in the Casimir vacuum state alone satisfies neither quantum inequalities nor averaged energy conditions. Such difference inequalities represent limits on the degree of energy condition violation that is allowed over and above any violation due to negative energy densities in a background vacuum state. In our simple two-dimensional model, they provide physically interesting examples of new constraints on negative energy which hold even when the usual AWEC, ANEC, and quantum inequality restrictions fail. In the limit when the size of the space is allowed to go to infinity, we derive quantum inequalities for timelike and null geodesics which, in appropriate limits, reduce to AWEC and ANEC in ordinary two-dimensional Minkowski spacetime. We also derive a quantum inequality bound on the energy density seen by an inertial observer in four-dimensional Minkowski spacetime. The bound implies that any inertial observer in flat spacetime cannot see an arbitrarily large negative energy density which lasts for an arbitrarily long period of time.

GENERAL RELATIVITY & QUANTUM COSMOLOGY, ABSTRACT GR-QC/9411053 From: "Haret Rosu" Date: 20 Nov 94 21:15:00 CST
On the assignment of frequency spectra to quantum vacuum effects, Author: Haret C. Rosu, Report: IFUG-25/94, I discuss in an introductory manner, i.e., in the form of comments on available references, the problem of assigning frequency spectra to such fundamental effects like Casimir, Hawking, Unruh, and squeezing effects. This may help to clarify their differences as well as their similarities.

GENERAL RELATIVITY & QUANTUM COSMOLOGY, ABSTRACT GR-QC/9411056 From: ulvi@tapir.Caltech.EDU (Ulvi Yurtsever) Date: Mon, 21 Nov 94 15:56:11 -0800
The averaged null energy condition and difference inequalities in quantum field theory, by: Ulvi Yurtsever
Recently, Larry Ford and Tom Roman have discovered that in a flat cylindrical space,

although the stress-energy tensor itself fails to satisfy the averaged null energy condition (ANEC) along the (non-achronal) null geodesics, when the ``Casimir-vacuum" contribution is subtracted from the stress-energy the resulting tensor does satisfy the ANEC inequality. Ford and Roman name this class of constraints on the quantum stress-energy tensor ``difference inequalities." Here I give a proof of the difference inequality for a minimally coupled massless scalar field in an arbitrary two-dimensional spacetime, using the same techniques as those we relied on to prove ANEC in an earlier paper with Robert Wald. I begin with an overview of averaged energy conditions in quantum field theory.

QUANTUM PHYSICS, ABSTRACT QUANT-PH/9502024 From: MANKO@napoli.infn.it
Date: Mon, 27 Feb 1995 16:32:21 +0200 (CET) Deformation of Partical Distribution Functions due to Q-nonlinearity and Nonstationary Casimir Effect, Author: V. I. Man'ko The geometrical phase is shown to be integral of motion. Deformation of particle distribution function corresponding to nonstationary Casimir effect is expressed in terms of multivariable Hermite polynomials. Correction to Planck distribution due to q--nonlinearity is discussed.

QUANTUM PHYSICS, ABSTRACT QUANT-PH/9503001 From: onofrio%38619.hepnet@Csa4.LBL.Gov
Date: Wed, 1 Mar 95 08:23:43 PST
Detecting Casimir Forces through a Tunneling Electromechanical Transducer Authors: Roberto Onofrio , Giovanni Carugno We propose the use of a tunneling electromechanical transducer to dinamically detect Casimir forces between two conducting surfaces. The maximum distance for which Casimir forces should be detectable with our method is around 1μm, while the lower limit is given by the ability to approach the surfaces. This technique should permit to study gravitational forces on the same range of distances, as well as the vacuum friction provided that very low dissipation mechanical resonators are used.

CONDENSED MATTER THEORY, ABSTRACT COND-MAT/9505023 From: moraes@guinness.ias.edu (Fernando Moraes)
Date: Fri, 5 May 95 09:35:57 EDT
Casimir effect around disclinations
Author: Fernando Moraes (Institute for Advanced Study, Princeton) This communication concerns the structure of the electromagnetic quantum vacuum in a disclinated insulator. It is shown that a nonzero vacuum energy density appears when the rotational symmetry of a continuous insulating elastic medium is broken by a disclination. An explicit expression is given for this Casimir energy density in terms of the parameter describing the disclination.

CONDENSED MATTER THEORY, ABSTRACT COND-MAT/9505108 From: moraes@guinness.ias.edu (Fernando Moraes)
Date: Tue, 23 May 95 17:12:35 EDT
Enhancement of the magnetic moment of the electron due to a topological defect Author: Fernando Moraes (Institute for Advanced Study, Princeton) In the framework of the theory of defects/three-dimensional gravitation, it is obtained a positive correction to the magnetic moment of the electron bound to a disclination in a dielectric solid.

QUANTUM PHYSICS, ABSTRACT QUANT-PH/9506005 From: JAEKEL Marc
Date: Wed, 7 Jun 1995 16:30:40 +0200
Mechanical Effects of Radiation Pressure Quantum Fluctuations Authors: Marc-Thierry Jaekel (Laboratoire de Physique Th\'eorique de l'Ecole Normale Sup\'erieure) , Serge Reynaud (Laboratoire Kastler-Brossel) As revealed by space-time probing, mechanics and field theory come out as complementary descriptions for motions in space-time. In particular, quantum fields exert a radiation pressure on scatterers which results in mechanical effects that persist in vacuum. They include mean forces due to quantum field fluctuations, like Casimir forces, but also fluctuations of these forces and additional forces linked to motion. As in classical electron theory, a moving scatterer is submitted to a radiation reaction force which

modifies its motional response to an applied force. We briefly survey the mechanical effects of quantum field fluctuations and discuss the consequences for stability of motion in vacuum and for position fluctuations.

QUANTUM PHYSICS, ABSTRACT QUANT-PH/9506006 From: JAEKEL Marc Date: Wed, 7 Jun 1995 16:58:17 +0200
Quantum Fluctuations and Inertia
Authors: Marc-Thierry Jaekel (Laboratoire de Physique Th\'eorique de l'Ecole Normale Sup\'erieure) , Serge Reynaud (Laboratoire Kastler-Brossel) Vacuum field fluctuations exert a radiation pressure which induces mechanical effects on scatterers. The question naturally arises whether the energy of vacuum fluctuations gives rise to inertia and gravitation in agreement with the general principles of mechanics. As a new approach to this question, we discuss the mechanical effects of quantum field fluctuations on two mirrors building a Fabry-Perot cavity. We first put into evidence that the energy related to Casimir forces is an energy stored on field fluctuations as a result of scattering time delays. We then discuss the forces felt by the mirrors when they move within vacuum field fluctuations, and show that energy stored on vacuum fluctuations contributes to inertia in conformity with the law of inertia of energy. As a further consequence, inertial masses exhibit quantum fluctuations with characteristic spectra in vacuum.

QUANTUM PHYSICS, ABSTRACT QUANT-PH/9506023 From: claudia@cromwell.physics.uiuc.edu (Claudia C Eberlein) Date: Thu, 15 Jun 95 11:13:57 -0500
Sonoluminescence as quantum vacuum radiation Author: Claudia Eberlein (Dept of Physics, UIUC, Urbana, IL) Sonoluminescence is explained in terms of quantum radiation by moving interfaces between media of different polarizability. It can be considered as a dynamic Casimir effect, in the sense that it is a consequence of the imbalance of the zero-point fluctuations of the electromagnetic field during the non-inertial motion of a boundary. The transition amplitude from the vacuum into a two-photon state is calculated in a Hamiltonian formalism and turns out to be governed by the transition matrix-element of the radiation pressure. Expressions for the spectral density and the total radiated energy are given.

HIGH ENERGY PHYSICS - THEORY, ABSTRACT HEP-TH/9508086 From: eli@ecm.ub.es (Emili Elizalde)
Date: Fri, 18 Aug 1995 10:14:50 +0200
A precise definition of the Casimir energy, Authors: K. Kirsten , E. Elizalde The somehow arbitrary definition of the Casimir energy corresponding to a quantum system in a d-dimensional ultrastatic spacetime ---profusely used in the last years--- which has been critized sometimes for adopting without a sound argument the minimal subtraction scheme, is shown to be completely equivalent to the definition steming naturally from the concept of functional determinant through the zeta-function prescription. This is done by considering the theory at finite temperature and by defining then the Casimir energy as its energy in the limit $T\to 0$. The ambiguity in the coefficient $C_{d/2}$ is understood to be a result of the necessary renormalization of the free energy of the system. As an example, the Casimir energy corresponding to a general $(1+2)$-dimensional toroidal spacetime with flat spatial geometry, parametrized by the corresponding Teichm\"uller parameters, and its precise dependence on these parameters is obtained under the form of an analytic function.

Ernest G. Cullwick. In his book "Electromagnetism and Relativity", published in 1957, was one of the first to provide an analysis of the probable coupling between EM and inertial fields. Cullwick realized that Maxwell's equations and most existing theories of electrodynamics assume that the mass of an electron is zero. At Maxwell's time this was a reasonable assumption. But it is well known today that electrons have mass, and therefore an inertial momemtum is always associated with an electric current. Cullwick suggested in his analysis that coupling terms between EM and inertia may be very small, but would likely appear sometime in the future as we go to higher current densities. And he was one of the first scientists to predict some of the odd effects which can now seen with superconductors. Cullwick was also one of the first to identify and attempt an analysis of the relativistic paradoxes and unusual effects which occur in a rotating EM field. His work still stands today as one of the only existing efforts to consider the problem of a rotating EM field.

AUTHOR: Cullwick, E. G. (Ernest Geoffrey), 1903-
TITLE: Electromagnetism and relativity : with particular reference
to moving media and electromagnetic induction / by E. G. Cullwick.
EDITION 2d ed.
PUBL.: New York : J. Wiley,
DATE: 1959 (2nd Edition)
SUBJECT: Electromagnetic theory, Relativity (Physics)

AUTHOR: Cullwick, E. G. (Ernest Geoffrey), 1903-
TITLE: The fundamentals of electro-magnetism by E.G. Cullwick.
EDITION 3rd ed.
PUBL.: London, Cambridge U.P.,
DATE: 1966 (3rd Edition)
SUBJECT: Electromagnetism

AUTHOR: Cullwick, E. G. (Ernest Geoffrey), 1903-
TITLE: The fundamentals of electro-magnetism; a restatement for
engineering students and others of physical and theoretical principles in accordance with modern scientific thought, by E. Geoffrey Cullwick ... With an appendix and numerous examples on the recently adopted M.K.S. system of practical units ...
PUBL.: New York, The Macmillan company; Cambridge, Eng., The
University press,
DATE: 1939
SUBJECT: Electromagnetism

If you work out the metric for EM waves circulating in a cavity you get some strange results. There is a preliminary discussion of this effect in the article by Houshang Ardavan, 'Gravitational Waves from Electromagnetic Waves' in the book "Classical General Relativity," edited by W.B. Bonner, I.N. Islam and M.A.H. MacCollum (Cambridge Univ. Press, 1984).
It is something I have seen done. At the point in an annular cavity where the phase velocity goes from less than c to greater than c, a term shows up in the derived metric of the system that looks like a source term. On the other hand you have assumed that the metric is source free in the EM region of the cavity. So you get a solution which contradicts the hypothesis that went into building the solution. You get something which is possibly unphysical. Now Einstein's equation and the associated geometry is pretty tricky and it is easy to get unphysical solutions. The final arbitors of whether a solution is satisfactory or not is physical reasonability and self consistancy (these are almost the same thing). The cavity problem seems very physically reasonable initially, but ends with a self-consistancy problem which appears to be unphysical. Also, Cauchy's theorem does not apply to this case since it becomes a mixed type problem (elliptic and hyperbolic PDEs), so the Hawking singularity theorems don't a priori apply. It is something very interesting, but to publish it with out being scoffed at would take a lot of work and possibly inventing some new math. -- Jim McClune, University of Missouri
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ROTATING FIELDS IN GENERAL RELATIVITY, by Islam, J.N. Begins with a short introduction to the relevant aspects of general relativity. This is followed by a detailed derivation of the Wehl-Lewis-
Papapetrou form of the stationary axially symmetric metric. The Kerr and Tomimatsu-Sato forms of the rotating interior and exterior solutions of the Einstein equations are then considered. Subject: physics
1985 6 X 9 122 pp. 4 diagrams
Hardback 0-521-26082-5 $47.95 (J7.99)

>If an EM field is somehow rotated extremely fast, shouldn't all matter be repelled from its center? -kgo.

How fast do you want it rotated? It's fairly simple to construct a system to produce rotating EM waves at whatever rotational velocity you wish by feeding a pair of broadside dipole arrays with quatrature phased waves. It is quite simple to construct a system that would have a rotational velocity of C within the uniform field area. It might also be fairly easy to do this with a Hemholtz coil arangement as well, but the broadside array will be much easier to do at easily engineerable frequencies. Some really interesting paradoxes come about when the rotational frequency is high enough so that the rotational velocity exceeds C within the uniform field area of the arrays or within the hemholtz coils. -- Robert Shannon
----

Ehrenfest Paradox (Ehrenfest, 1909) --
The special relativistic "paradox" involving a rapidly rotating disc. Since any radial segment of the disc is perpendicular to the direction of motion, there should be no length contraction of the radius; however, since the circumference of the disc is parallel to the direction of motion, it should contract.

Question -- by Kung Lo (October 1995):
Take a rigid disk of radius R and spin it up to angular velocity . As seen by an observer S that is at rest in the center of the disk, the radius is still R, but the circumference is contracted by the Lorentz effect. How is this possible?
More physically, if a fixed ring is just outside the spinning disk and placed with equally spaced markers on the rim of the disk and on the fixed ring, I know by symmetry that, when one marker on the disk is aligned with a marker on the ring, all pairs of markers must be aligned. This contradicts the fact that, for observer S, the distance between successive markers on the disk is reduced by the Lorentz factor.

Answer -- provided by David Djajaputra (November 1995): It seems that the rotating disk paradox (it turned out to be Ehrenfest's paradox) has been extensively analyzed by many people (including Einstein himself, who developed general relativity to answer this problem, as one author speculates...). This I found from a nice paper :

O. Gron, "Relativistic description of a rotating disk" Am. J. Phys. V43, 869 (1975), and all the references therein.

The key sentence in Gron's paper is at the end of Section IV: "By definition a Born rigid motion of a body leaves lenghts unchanged, when measured in the body's proper frame . (...) A Born rigid motion is not a material property of the body, but the result of a specific program of forces designed to set the body in motion without introducing stresses. (...) A transition of the disk from rest to rotational motion, while it satisfies Born's definition of rigidity, is a kinematic impossibility"

With this kinematics the radius is R and the circumference is as measured by observer S (lab frame), but an observer riding on the disk will measure a distance R to the center and a distance around the circumference (he can do this measurement by slowly walking around the spinning disk with a meter tape). This is consistent with the usual Lorentz contraction . The point is that this is NOT a Born rigid motion. There is much more in Gron's paper. -- Vittorio Celli
----

Several key pharases keep popping up regarding rotating fields, powerful magnetic pulsed fields, and 90 degree cross-field phase shifts. For example, Preston Nicholes describes a device known as a Delta T antenna in the Montauk series of books. The Delta T antenna is described as a pyramidal structure, but lets just take two square loops, placed at 90 degrees to each other, and feed these two loops with an RF signal, also with a 90 degree phase shift, we will produce a rotating magnetic field within the loops (these loops share a common center point, and each loop is in a plane 90 degrees from the other) The speed of rotation of this magnetic field is a direct function of the frequancy of the applied RF signal. At the center of the antenna, the rotational velocity is zero, but as you move out from the center, and rotational velocity increases. At some distance from center would reach the speed of light, dependant of the frequancy used. One could imagine that the rotational velocity of this rotating magnetic field could reach the speed of light within the antenna structure itself if a way could be found to make the antenna much larger than a normaly resonant antenna would be for that same frequancy. At several hundred megahertz, a two meter per side square loop would have a rotational velocity well in excess of the speed of light within the antenna structure itself.

What effect would there be at the boundry where the rotational velocity reached, and then exceeded the speed of light. How could the magnetic field even propogate to the center of the antenna structure if it would have to move faster than light to reach that space? If hemholtz coils were used instead of loops, the magnetic field strength would be uniform inside the structure, how could the field strenght be uniform if there is not sufficient time for the field to propogate through the space inside the structure itself?

Could such an effect actually generate a wormhole like phenomena, at energy levels far below that of neutron stars and such? As the causal mechanism, the magnetic field, is in roation, would this describe a traversable worm hole as has been postulated in relationship to rotating black holes? -- Robert Shannon

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Aono, Osamu, 1937-

Rotation of a magnetic field / Osamu Aono and Ryo Sugihara. Nagoya, Japan : Institute of Plasma Physics, Nagoya University, 1986. 6 p. ; 30 cm. LC CALL NUMBER: QC717.6 .N35 no. 792 (ALTERNATE CLASS QC754.2.M3) SUBJECTS: Magnetic fields. Electrodynamics. Research report (Nagoya Daigaku. Purazumu Kenkyujo) ; IPPJ-792. --
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Let me clear this up a bit, the two coils are acting as antenne already, producing the rotating field by vector sumnation of the radiated quatrature phased EM waves. The loops would be operating as the driven elements of a cubical antenne, not as coils as such. If you prefer, substitute the two loop antenne with a pair of crossed dipoles at 90 degrees, this will also produce the rotating field, but the center will be occupied by the dipoles rather than be open as with loop antenne of by using sets of broadside arrays. Note that this is not the same as the rotational speed reaching c inside the "uniform field" area, as described earlier. It's simple a tool to understsand the generation of the rotating field and the relationship between applied frequency and the resultant roational speed. Rather than loop elements, in practice you might use a phased array of dipole elements that produces a constant phase plane wave, not unlike a pair of hemholtz coils produced a uniform field within the coil sets. Four of these "broadside arrays" would from the four sides of a cube, inside of which you could induce the fast rotating fields from the radiated EM waves. In all cases, the driven elements are lauching EM waves a c. Only the vector sum of the two (of four) quatrature fields is in rotation, which leads us back the the question of what happens as the rotational velocity of the sum of these EM fields reaches c within the field generator, and there is not sufficient time for the fields to propogate accross the Vr=c boundry?

This is the point where two different physists have tried to lead me dowm the garden path of "red shifted magnetic fields". I'm not sure I'm ready to buy that concept just yet.

-- Robert Shannon

GENERAL RELATIVITY & QUANTUM COSMOLOGY, ABSTRACT GR-QC/9601034 From: Tevian Dray Date: Mon, 22 Jan 1996 10:57:03 PST

The Rotating Quantum Vacuum

Author(s): Paul C. W. Davies , Tevian Dray , Corinne A. Manogue Report-no: ADP 95-43/M36 (University of Adelaide) We derive conditions for rotating particle detectors to respond in a variety of bounded spacetimes and compare the results with the folklore that particle detectors do not respond in the vacuum state appropriate to their motion. Applications involving possible violations of the second law of thermodynamics are briefly addressed.

I'm also saying that a pair of crossed coils will start behaving differently when the driving frequency is so high that the field lines near them try to exceed the speed of light. At low frequencies the coils create a rotating magnetic field. At high frequencies they send out radio waves having a rotating field vector (circularly polarized waves, in other words.) WITHIN the volume of the coils the fields still rotate, at least until the frequency is raised so high that the coils are many wavelengths across. At these frequencies the fields in the center of the crossed coils would be of complex shape, maybe some kind of contracting spiral. (Which is interesting, because at very high frequencies there would be a "hot spot" at the exact center of the crossed coils.) -- Robert Shannon
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On similar topic: anyone ever heard of the "CFA antenna" flap in the UK? CFA is for "crossed-field antenna." There were a bunch of articles and letters to the editor in EWW, "Electronics and Wireless World," the British engineering mag. The CFA-believers though they had discovered a way to make 1-foot antennas which were efficient at 100-meter wavelengths. The key to the CFA was to create the e- and b-fields separately: feed both a coil-loop and a pair of capacitor-spheres with separate high-current and high-voltage signals respectively, orient them 90deg to produce a broadside wave, shift the phases with L/C networks to form the proper EM wave (90? zero?), and then obtain a powerful EM emission from a tiny antenna. There was a great quantity of argument and name-calling over this, all done in slow-motion over many months of letters in the letters-to-the-editor column. Then it just died away. Either the pro-CFA side couldn't prove that it worked, or nobody believed the proof they did find.
-- William Beaty

And some comments about rotating EM fields by Dr Dennis Cravens in a report titled "Electric Propulsion Study", done for the Astronautics Laboratory at Edwards AFB. August 1990. Dennis Cravens was formerly with SAIC Corp, and is now working with CETI in development of cold fusion. Anyway, here's some things he says in the electric propulsion report about the "peculiarities" of a rotating magnet:

ROTATION OF MAGNETS - There is a continuing debate in physics as to the reality of the magnetic field. The prime question is whether the axial magnetic field of a bar magnet rotates with the magnet or is stationary. The Faraday homopolar generator dates back to the 1830s. DePalma, Tewari, and others have attempted to utilize the Faraday generator to produce more power than needed to run it. Most objective reviews of the work have, however, failed to see such effects.

It is doubtful that these claims will be independently validated and even more doubtful that they will lead directly to a propulsive system. However, the work on homopolar generators as high current devices is reasonable and may be useful for ground uses. The angular momentum complications seem to rule the system out for any practical space applications.

SEARL EFFECT - The Searl Effect is a separate issue from homopolar generator above. Searl has claimed to produce disk levitation by rapidly rotating magnets. There have been claims of anti-gravity, high electric fields, perpetual motion, inertial loss, and gas ionization. All these claims come from Searl or those supportive of his work and no outside witnesses are available. Searl has not supplied any technical data or specifics of the operation in any easily referenced source. It is not recommended that his work be experimentally followed by the USAF. It is worth noting however, that a rotating magnet does have some definite theorectical peculiarities.

Through the years there have been many interesting developments concerning the Faraday Homopolar generator. DePalma has claimed to get more energy out than is supplied to the the generator. None of the claims seem to withstand careful examination and no machine has ever been made self driving. The underlying reason that such claims continue to surface is that rotating magnetic fields are extremely difficult to handle within existing theories. This is because for a rotating frame there is a distance (removed from the axis) which is travelling at velocities greater than c. Although the distance is not withing any real physical object, it's existence within the mathematical development greatly complicates any calculations.

DePalma B.E., "Electro-Mechanical Device for the Amplification of Electrical Power", The New Age Science Magazine, No 7, 1980

Tewari P., "Generation of Electrical Power from Absolute Vacuum by High Speed Rotation of Conducting Magnetic Cylinder", Tech. Rep. Dept. of Atomic Energy, Bombay India, 1985

Searl, J.R.R., British provisional patent specification #57578, 1970 ---------
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These articles are indicative of studies of EM waves and rotating bodies. It appears that when EM waves pass through rotating dielectrics some unusual effects are predicted. This may lead to some interesting future technology.
-- Dr Dennis Cravens

"Some Remarks on Scattering by a Rotating Dielectric Cylinder", D. Schreiber, Journal of EM Waves and Applications, Vol 2 No2 1988

"Rotating Bodies and Electrodynamics in a Rotating Reference Frame", I.B. Zeldovich and L.V. Rozhavskii, Radiofizka Vol 29 No 9, 1986 -------------
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-- Here's an interesting news brief from Infinite Energy magazine, July/Aug 1995, Dr Eugene Mallove - editor. (603)-228-4516

A bombshell paper has just been published in the American Journal of Physics, Vol 63 No 8, August 1995, pages 694-705, "Maxwell's Equations in a Rotating Medium: Is There a Problem?" by Gerald N. Pellegrini and Arthur R. Swift (the latter of the Dept of Physics and Astronomy, University of Massachusetts, Amherst MA)"

The paper is a direct challenge to Special Relativity. It proves one of two things about a classic 1913 experiment of Wilson and Wilson that was used to verify the prediction of relativity that "a moving magnetic dipole develops an electric dipole moment.' The conclusion of the paper is that Special Relativity does NOT agree with this experiment -- and no one has ever challenged the quality of the experiment.

Peregrinni told Infinite Energy that he thinks that all of relativity as well as Maxwell's equations as descriptors of EM radiation are now called into question. -------------------------
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The origin of the Montauk Project dates back to 1943 when radar invisibility was being researched aboard the USS Eldridge. As the Eldridge was stationed at the Philadelphia Navy Yard, the events concerning the ship have commonly been referred to as the "Philadelphia Experiment." The objective of this experiment was to make the ship undetectable to radar and while that was achieved, there was a totally unexpected and drastic side effect. The ship became invisible to the naked eye and was removed from time and space as we know it. It went into 10-dimensional hyper-space. For further info into this, read the book called "Hyperspace" by Dr.

Michio Kaku. A movie called "The Philadelphia Experiment" was made, but delayed for two years as the Pentagon was able to halt its release. After the war, research continued under the tutelage of Dr. John Von Neumann who had directed the technical aspects of the Phily Experiment. A massive human factor study was also begun at Brookhaven National Labs on Long Island, New York -- known as the Phoenix Project. The Montauk Project culminated on August 12, 1983. A full blown time portal was fully functioning, but things were out of control and the project was crashed. An unauthorized video has been widely distributed regarding this story and several lectures has been given on the Montauk Project. One science reported for the New York times started the project but tacked off when he discovered to his own surprise that the Montauk Project was indeed real.

Three books have been released by Preston Nichols, who was involved in the Project, and Peter Moon. They are

1) The Montauk Project: Experiments in Time - 1992 2) Montauk Revisited: Adventures in Synchronicity - 1994 3) Pyramids of Montauk Explorations in Consciousness-1995 This coming year, 1996, the next book will be out and the title will be "Montauk Reconciled"

-- Richard Frager

HIGH ENERGY PHYSICS - PHENOMENOLOGY, ABSTRACT HEP-PH/9412234 From: Michael Martin Nieto 505-667-6127 Date: Mon, 5 Dec 94 09:52:27 -0700

THEORETICAL MOTIVATION FOR GRAVITATION EXPERIMENTS ON ULTRA-LOW ENERGY ANTIPROTONS AND ANTIHYDROGEN

Authors: Michael Martin Nieto , T. Goldman , John D. Anderson , Eunice L. Lau, J. Perez-Mercader

Comments: Written version of invited contribution to LEAP'94: Third Biennial Conference on Low-Energy Antiproton Physics. We know that the generally accepted theories of gravity and quantum mechanics are fundamentally incompatible. Thus, when we try to combine these theories, we must beware of physical pitfalls. Modern theories of quantum gravity are trying to overcome these problems. Any ideas must confront the present agreement with general relativity, but yet be free to wonder about not understood phenomena, such as the dark matter problem and the anomalous spacecraft data which we announce here. This all has led some ``intrepid'' theorists to consider a new gravitational regime, that of antimatter. Even more ``daring'' experimentalists are attempting, or considering attempting, the measurement of the gravitational force on antimatter, including low-energy antiprotons and, perhaps most enticing, antihydrogen.

HIGH ENERGY PHYSICS - EXPERIMENT, ABSTRACT HEP-EX/9412018 From: PHILLIPS@hep.phy.duke.edu

Date: Fri, 30 Dec 1994 16:03:31 -0500 (EST)

A Technique for Directly Measuring the Gravitational Acceleration of Antihydrogen, By: Thomas J. Phillips, Duke University Durham Comments: Written version of invited contribution to LEAP'94: Third Biennial Conference on Low-Energy Antiproton Physics. The gravitational force on antimatter has never been directly measured. A method is suggested for measuring the acceleration of antimatter $(\overline g)$ by measuring the deflection of a beam of neutral antihydrogen atoms in the Earth's gravitational field. While a simple position measurement of the beam could be used, a more efficient measurement can be made using a transmission interferometer. A 1\% measurement of $\overline g$ should be possible from a beam of about 100,000 atoms, with the ultimate accuracy being determined largely by the number of antihydrogen atoms that can be produced. A method is suggested for producing an antihydrogen beam appropriate for this experiment.

HIGH ENERGY PHYSICS - PHENOMENOLOGY, ABSTRACT HEP-PH/9509336 From: Michael Martin Nieto 505-667-6127 Date: Tue, 19 Sep 95 14:08:11 -0600

Antimatter Gravity and Antihydrogen Production Authors: Michael H. Holzscheiter , T. Goldman , Michael Martin Nieto Certain modern theories of gravity predict that antimatter will fall differently than matter in the Earth's gravitational field. However, no experimental tests of gravity on antimatter exist and all conclusions drawn from experiments on matter depend, at some level, on a specific model. We have proposed a direct measurement that would compare the gravitational acceleration of antiprotons to that of negatively charged hydrogen ions. Substantial progress towards the development of this experiment has been achieved. Based on our work a number of alternative proposals for measuring ``g'' on both charged and neutral antimatter have been made. We summarize the present status of our experiment and also discuss the steps that would be necessary to produce antihydrogen in an environment suitable for gravity measurements.

Hi Robert, I have one reference for you. The book is called "Suppressed Inventions and other Discoveries". It's an anthology edited by Jonathon Eisen. Authors include: Dr. Brian O'Leary, Christopher Bird, Jeanne Manning, Barry Lynes, and others. As well as Townsend Brown, the inventers/doctors (as well as inventions the book also covers various cancer treatments which have had research suppressed) who are discussed include Naessons, RifeHoxsey, Gerson, Tesla, Brown, Reich and others.

The book covers free energy, various "unfree" though different motive technologies, cancer cures which have worked but not seen approval by the AMA, Roswell, the Mars face, and as a delight to conspiracy buffs, there are also chapters on how various Government bodies have suppressed these technologies, as well as how the AMA came to be all powerful in the field of suppressing alternate treatments.

The book is published by:
Auckland Institute of Technology Press
Private Bag 92006
Auckland, New Zealand

ISBN No. 0-9583334-7-5

For further research, consult the following sources:

Fer-de-Lance by T.E. Beardon
Tesla Book Company
P.O. Box 121873
Chula Vista, CA 91912 USA

Leading Edge Research Group
(Leading Edge Journal #77 12/94)
P.O. Box 7530 Ste 58
Yelm, Washington 98597 USA

Nexus Magazine
P.O. Box 66
8400 AB Gorredijk
The Netherlands
Tel/Fax: 31-(0)5133-5567

The information on the electrogravitics reference list which is of particular interest to me are the Laithwaite and Wallace references. I think my work (Electrical-Dipole Theory of Gravitation) explains what they were observing and why. Here are some additional references. -- Ralph Sansbury

Fischbach, Sudarsky, Szafer, Talmadge, and Aronson in "Reanalysis of the Eotvos Experiment" (Phys Rev Let vol 56 p3 6/1/86)

J.H. Pratt and G.B. Airy 1855 Phil Trans v145

Fredrich Zollner, Explanation of Universal Gravitation through the Static Action of Electricity and the General Importance of Weber's Laws, 1882

Immanuel Velikovsky, Cosmos without Gravitation, 1964

V. A. Bailey In the May 14 , 1960 issue of Nature

P.M.S. Blackett In the May 17, 1947 issue of Nature

T. Gold in a later issue (April 2, 1949) of Nature

Henry Wallace US patent number 3 626 605

P.S. Wesson Phys Rev D v23 p1730 (1981)

Sansbury R.N. Electrical Engineering Times (12/28/87)

Sansbury R.N. US patent number 4,355,195

Sansbury R.N. Rev. Sci. Instr. (3/85)

Bartlett D.F. Rev.Sci. Instr. (10/90)

Peter Graneau, Nature v295 1982 p311

Weiskopf M.C., Carrico, Gould, Lipworth and Stein, Physical Review Letters 1968, vol21 p1645

Coles and Good, Physical Review 1946 p979

Kaufmann W. p502 in World of the Atom by H. Bourse and L. Motz

W.J. Duffin, Electricity and Magnetism Wiley 1973

R.A. Tricker, Early Electrodynamics Pergamon Oxford 1965 ---------------------
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Paper: gr-qc/9410019
From: Peter Marzlin Date: Mon, 17 Oct 94 12:50:28 +0100
THE DIPOLE COUPLING OF ATOMS AND LIGHT IN GRAVITATIONAL FIELDS, Karl-Peter Marzlin, 10 pages, LaTeX
The dipole coupling term between a system of N particles with total charge zero and the electromagnetic field is derived in the presence of a weak gravitational field. It is shown that the form of the coupling remains the same as in flat space-time if it is written with respect to the proper time of the observer and to the measurable field components. Some remarks concerning the connection between the minimal and the dipole coupling are given.

The level of difficulty in the above paper is well beyond my grasp. But what is clear is that it presents an analysis which strongly suggests that the textbook wavefunctions for electrons within atomic matter can be best described by the dipole coupling rather than the coulomb gauge. The paper also relates the dipole coupling to a weak gravitational field. The last paragraph of the paper provides substance to the idea that gravity is at least in part, an electric dipole phenomena. Here is the last paragraph:

"It is interesting to make a comparison of the present results with the well known formal equivalence between the Maxwell field in curved space and in a dielectric medium (23). In this approach one defines a formal dielectric displacement vector to describe the influence of gravity on the Maxwell field. In the absence of particles, i.e. for vanishing polarisation P, the formal electric displacement agrees with the vector delta defined above. Also the coupling of the Poynting vector to the rotation occurs in the energy of the formal Maxwell field."

The paper referenced (23) is:

A.M. Volkov, A.A. Izmest'ev, and G.V. Skrotskii, Soviet Physics JETP 32, page 686, (1971)

Note: There are a variety of other theories and experiments which attempt to show that a static gravitational field is identical to that which results from electric dipole moments -- a polarisation of the vacuum. And conversely, it is well know that if you accelerate a dielectric material, or in "equivalence" subject a dielectric material to a gravitational field or other mechanical force -- an electric field due to dipole moment (polarisation P) will be generated within the material. This effect is especially prevalent in structured crystal dielectrics (piezoelectric materials), which are used as transducers in accelerometer sensors. You can also find piezoelectric material, and conversion of mechanical force to a high voltage electric field, in push-button spark igniters used on gas grills and cigarette lighters.

Here's a thought. To enlighten those folks who continue to stubbornly try to debunk the evident relationship between gravitation and electromagnetics -- insert one of these spark igniters in a neuro-sensitive body cavity, and click it as many times as necessary.

One issue with the electrostatic dipole hypothesis is that once the magnetic effects of spin etc have been considered there is no evidence of such dipoles inside atomic nuclei and electrons. However if magnetic properties of nuclei and electrons can be represented in terms of electrostatic dipoles as recent experiments and theoretical discussion seem to indicate then this objection is avoided. The dipole can be produced by a negatively oriented particle orbiting a positive central particle so that the combination has a net positve charge (see Rev Sci Instr Mar 1985 and Geomagnetism: Gravity Measured by Magnetic Materials, ICP Press, Box 492 NY NY 10185 $25US 1994 by R Sansbury) An added benefit: the observed quadrapole in nuclei and electrons makes more sense in a physically real Taylor expansion by the inclusion of an observed dipole term as well; that is the dipole term is not observed because its effects are wrongly attributed to another cause, magnetism; thus magnetism is properly regarded as a derived apparently separate force like the Coriolis sideways force on bodies moved radially on a rotating platform.
-- Ralph Sansbury

About electric dipole precession. The article "Electricity" in Britannica includes a resonance equation for dipole precession in dielectrics. It was identical in form to the one used in magnetic resonance, except for the obvious differences in units. Dielectric precession (resonance) frequencies were in the optical range. Brown didn't use resonance; but he did use a steady frequency. His frequency, too, would damp out if it were discontinued. Greater results than Brown's could probably be achieved with lasers. But I doubt you'll find a better description of dielectric dipole resonance. The Britannica article gives the mathematics.
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van der Waals force (J.D. van der Waals) -- Forces responsible for the non-ideal behavior of gases, and for the lattice energy of molecular crystals. There are three causes: dipole-dipole interaction; dipole-induced dipole moments; and dispersion forces arising because of small instantaneous dipoles in atoms.

"The Electric Dipole Moment of the Electron", Bernreuther & Suzuki, Reviews of Modern Physics, April 1991 vol 63 no 2 -- An electron or any other elementary particle can possess an electric moment (EDM) only by virtue of an interaction that violates parity and time-reversal invariance. The question of whether an electron EDM exists is thus related directly to the unsolved problem of CP violation. According to the standard model, in which CP violation is accounted for in terms of the Kobayashi-Maskawa matrix, the electron EDM is predicted to be far too small to be observed experimentally. However, a number of alternative teoretical models of CP violation predict larger values of the electron EDM. These models are of special interest now, when experimental limits on the electron EDM are improving substantially.

"The Electron Electric Dipole Moment for a CP-violating Neutral Higgs Sector", J.F. Gunion, Physics Letters: Part 8, Nov 8 1990

"New Experimental Limit on the Electron Electric Dipole Moment", Abdullah & Commins, Physical Review Letters, Nov 5 1990

"The Standard Model Prediction for the Electric Dipole Moment of the Electron", F. Hoogeveen, Nuclear Physics B, Sep 10 1990

"Electric Dipole Moment of the Electron and the Neutron", S.M Barr, Physical Review Letters, July 2 1990, Vol 65 No 1

"Effective Hamiltonian for the Electric Dipole Moment of the Neutron", Boyd, Gupta & Trivedi, Physics Letters: Part 8, May 24 1990

"A search for the Electric Dipole Moment of the Neutron", K.F. Smith, Physics Letters: Part 8, Jan 4 1990, Vol 234 No 1/2

"Interpretation of the Neutron Electric Dipole Moment: Possible Relationship to Epsilon", Booth, Briere & Sachs, Physical Review D Jan 1 1990, Vol 41 No 1

"Inclusion of the Toroidal-Moment Contribution in the Probability of the Electric Dipole Transition", R.G. Nazmitidinov, Soviet Journal of Nuclear Physics, Sep 1 1990, Vol 53 No 2 -------------------------------------
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But what is the thing in atomic nuclei that collectively produces the gravitational field of the Earth etc. and which causes individual nuclei to react in the prescribed manner? The hypothesis proposed is that atomic nuclei contain small electrostatic dipoles (10^-37C.-m.) with radial and longitudinal components transverse to the west to east spinning direction of the Earth etc. Such dipoles explain the nuclear magnetic moment and electrostatic quadrapole moment inferred from the hyperfine spectra emitted by some excited atoms and the deflection of molecules such as orthohydrogen in a magnetic field (but not parahydrogen because the magnetic moments are anti parallel in pairs and cancel)

The Cavendish measurement of the horizontal gravitational force between two lead spheres instead of being attributed to the small masses of each can be attributed to the small horizontal component of the radial force, directed to the center of the Earth, due to the mass of the Earth on each of the small masses. That is gravity is not a property of mass per se but only of spinning mass.

The atomic nuclei of all elements, except iron, cobalt, and nickel primarily, tend to line up in the direction of the surrounding atomic nuclei when the bulk object of which they are a part is moved but in the case of the magnetic elements the bulk material must also move to complete the required alignment, hence the north south and downward movement of a magnetized steel compass needle. Hence the Wilson-Blackett proportionality between the angular momentum of planets, stars etc and their magnetic moment where the constant of proportionality is the square root of the gravitational constant divided by the speed of light. For more information see Science News Aug 6 '94 p82. - Ralph Sansbury
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Edward Teller, "Electromagnetism and Gravitation", Proceeds of the National Academy of Science, Vol 74 No 4, Pages 2664-2666.

In this paper Dr Teller suggests some clues about the coupling between electromagnetism and gravitation. In the first part of his paper Teller describes how an electric field due to polarization can be induced in a dielectric material which is subject to angular or linear acceleration, or if subject to a gravitational field. In the second part of the paper Teller describes, using purely dimenensional analysis, how a magnetic field might be produced by a spinning mass. He also comments that the magnitude of this magnetic field might be exceedingly small, and notes that a "numerical" factor could exist which might act to increase the magnitude of the field.

(Note: It is speculated by others that alignment of microscopic particles with the macroscopic spin axis of the earth, could result in a large "numerical" factor. Fact is, the earth does have a fairly large measurable magnetic field, about which there are a variety of theories as to the origin.)

Paper: hep-th/9506049
From: HORIE@dipmza.physik.Uni-Mainz.DE
Date: Thu, 08 Jun 1995 11:23:23 +0100
Title: New Insight into the Relation between Torsion and Electromagnetism Author: Kenichi Horie (Mainz Univ.)
Report-no: MZ/TH 95-16
In several unified field theories the torsion trace is set equal to the electromagnetic potential. Using fibre bundle techniques we show that this is no leading principle but a formal consequence of another geometric relation between space-time and electromagentism.

HIGH ENERGY PHYSICS - THEORY, ABSTRACT HEP-TH/9409018 From: HORIE@VIPMZw.physik.Uni-Mainz.DE
Date: Sat, 03 Sep 1994 10:27:48 +0100
GEOMETRIC INTERPRETATION OF ELECTROMAGNETISM IN A GRAVITATIONAL THEORY WITH SPACE--TIME TORSION BY KENICHI HORIE, INSTITUT FUR PHYSIK, JOHANNES GUTENBERG--UNIVERSIT"AT MAINZ, D--55099 MAINZ, GERMANY, A complete geometric unification of gravity and electromagnetism is proposed by considering two aspects of torsion: its relation to spin established in Einstein--Cartan theory and the possible interpretation of the torsion trace as the electromagnetic potential. Starting with a Lagrangian built of Dirac spinors, orthonormal tetrads, and a complex rather than a real linear connection we define an extended spinor derivative by which we obtain not only a very natural unification, but can also fully clarify the nontrivial underlying fibre bundle structure. Thereby a new type of contact interaction between spinors emerges, which differs from the usual one in Einstein--Cartan theory. The splitting of the linear connection into a metric and an electromagnetic part together with a characteristic length scale in the theory strongly suggest that gravity and electromagnetism have the same geometrical origin.

"Gauge Invariant Electromagnetic Coupling with Torsion Potential", Richard T. Hammond, General Relativity and Gravitation, Vol 23 No 11 1991 Electromagnetism is coupled to torsion in a gauge invariant manner by relaxing minimal coupling and introducting into the Lagrangian a term bilinear the electromagnetic field tensor and its torsion potential. The resulting coupling between electromagnetism and torsion is examined and a solution corresponding to traveling coupled waves is given. Since torsion is usually regarded as resuting from the spin of a body, this might establish a classical relationship between charge and spin. The results suggest that the effect should be looked for in high intensity electric fields of low frequency.

"Detecting Torsion from Massive Electrodynamics", L.C. Garcia de Andrade, and M. Lopes, General Relativity and Gravitation, Vol 25 No 11 1993 A new method of detecting torsion in the case of massive electrodynamics is proposed. Several authors have proposed methods for the detection of torsion in theories of the Einstein-Cartan type, and also in theories where the torsion field propogates. These theories are based on the studies of Dirac test particles, which have spin like the electron, and the gyroscope-like precession of these atomic particles. The interaction energy between the torsion vector Q, and an electric dipole p, is given by (p dot Q).

AUTHOR(s): de Andrade, L.C. Garcia
TITLE(s): Electron gyroscopes to test torsion gravity?
In: Il nuovo cimento delle societa italiana di fisic OCT 01 1994 v 109 n 10 Page: 1123

AUTHOR: De Sabbata, Venzo.
TITLE: Spin and Torsion in Gravitation
by Venzo de Sabbata, and C. Sivaram.
PUBL.: Singapore ; River Edge, NJ : World Scientific,
FORMAT: xii, 313 p. : ill. ; 23 cm.
DATE: 1994
SUBJECTS: Torsion, Gravitation

AUTHOR: De Sabbata, Venzo.

TITLE: Introduction to Gravitation
by Venzo de Sabbata and Maurizio Gasperini. PUBL.: Singapore ; Philadelphia : World Scientific,
FORMAT: ix, 346 p. : ill. ; 23 cm.
DATE: 1985
SUBJECTS: General relativity, Torsion, Gravitation

AUTHOR: NATO Advanced Study Institute on Cosmology and Gravitation
(1979: Bologna, Italy)
TITLE: Cosmology and Gravitation: Spin, Torsion, Rotation, and
Supergravity
Edited by Peter G. Bergmann and Venzo De Sabbata. PUBL.: New York : Plenum Press : NATO Scientific Affairs Division,
FORMAT: ix, 510 p. : ill. ; 26 cm.
DATE: 1980
SERIES: NATO Advanced Study Institutes Series v 58 Series B Physics
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CONFERENCE :International Conference on Magnetic and Electric Resonance and Relaxation (1962: Eindhoven)
TITLE :Magnetic and electric resonance and relaxation; proceedings of the XIth Colloque Ampere, Eindhoven, July 2-7, 1962. PUBLISHED :Amsterdam, New York, North-Holland Pub. Co.; Interscience Publishers, 1963.
DESC :xi,789p. illus.,diagrs.,tables. 24cm. ------------------------------------
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The Lorentz-Dirac equation is a purely classical expression for the electromagnetic force on a point charge, including the self-force from the particle's own radiation. It's a strange equation, with solutions that are manifestly unphysical under certain circumstances. If you want to know more about it, you might want to look at:

S. Parrott, Relativistic Electrodynamics and Differential Geometry, Springer-
Verlag, 1987.

GENERAL RELATIVITY & QUANTUM COSMOLOGY, ABSTRACT GR-QC/9403058 PHYS. REV. D50 (1994 3867) carroll@marie.mit.edu (Sean Carroll) Tue, 29 Mar 1994 19:57:32 -0500
CONSEQUENCES OF PROPAGATING TORSION IN CONNECTION-DYNAMIC THEORIES OF GRAVITY, BY SEAN M. CARROLL AND GEORGE B. FIELD, 16 PAGES PLUS ONE FIGURE (PLAIN TEX), MIT-CTP #2291.
We discuss the possibility of constraining theories of gravity in which the connection is a fundamental variable by searching for observational consequences of the torsion degrees of freedom. In a wide class of models, the only modes of the torsion tensor which interact with matter are either a massive scalar or a massive spin-1 boson. Focusing on the scalar version, we study constraints on the two-dimensional parameter space characterizing the theory. For reasonable choices of these parameters the torsion decays quickly into matter fields, and no long-range fields are generated which could be discovered by ground-based or astrophysical experiments.

GENERAL RELATIVITY & QUANTUM COSMOLOGY, ABSTRACT GR-QC/9304047 From: KUBYSHIN%EBUBECM1.BITNET@FRMOP11.CNUSC.FR Date: Sun, 02 May 93 12:55:30 BCN
INVARIANT CONNECTIONS WITH TORSION ON GROUP MANIFOLDS AND THEIR APPLICATION IN KALUZA-KLEIN THEORIES, KUBYSHIN YU.A., MALYSHENKO V.O. AND MARIN RICOY D. Invariant connections with torsion on simple group manifolds S are studied and an explicit formula describing them is presented. This result is used for the dimensional reduction in a theory of multidimensional gravity with curvature squared terms on M^{4} times S. We calculate the potential of scalar fields, emerging from extra components of the metric and torsion, and analyze the role of the torsion for the stability of spontaneous compactification. ------------

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Subject: Antigravity in Jane's
From: "Terry Colvin"

"All those interested in advanced propulsion concepts should check out Jane's Defence Weekly, 10 June 1995. An article discusses anti-gravity schemes and shows drawings of sauceroid vehicles from British Aerospace among others. Area 51 is mentioned, as well as an unclassified paper done for the USAF by Science Applications International Corp. in 1990. The subject was [Electric Propulsion], a[n] euphemism for anti-gravity according to Jane's. Michael Flora"

Anti-Gravity for Real -- Discussed in Jane's Defence Weekly

Jane's Defence Weekly is a most respected journal in the defense industry. Jane's has often been the first to break the news about secret development of radically new technologies and equipment.

Jane's Defence Weekly of 10 June 1995, has an article about advanced aerospace technologies, written by Nick Cook. The idea of anti-gravity is taken seriously and is auspicouly present throughout the article -- including three artist renditions of future anti-gravity based craft.

The Jane's article commences with a mention of anti-gravity technology, and also ends with a few paragraphs discussing anti-gravity. In between is the bulk of the article, which consists of discussion of "conventional" subjects, including: Hypersonics, Gas Turbine Inrements, The Super Cockpit, and Stealth.

At the start of the Jane's article there is some information from the Gravity Rand Report on Electrogravitics which was done for the USAF in 1956, and was recently declassified. Here's an excerpt from the beginning of the Jane's article.

Take this example from a specialist US aviation magazine in 1956. "We're already working with equipment to cancel out gravity," Lawrence D Bell, founder of the company that bears his name was quoted as saying. Bell, apparently, was not the only one working in this field. Others said to be seeking to master this arcane 'science' included the Glenn L Martin Company, Convair, Lear, and Sperry Gyroscope. Within a few years we were assured, aircraft, cars, submarines and power stations would all be driven by this radical new propulsion technology. Sadly it was not to be.

Here's the ending section of the Jane's article.

BEYOND 2001
Groom Lake Nevada is the epicentre of classified USAF research into Stealth and other exotic aerospace technologies. Several years after the collapse of the Soviet threat, activity and investment at this remote, highly secret air base (so secret its prescence is, as yet, unacknowledged by the US government) is still on the increase. While research into less sensitive technologies such two-dimensional thrust-vectoring and advanced short take-off and vertical landing (ASTOVL) are pursued in the open at nearby Edwards AFB in California, Groom Lake is set to hang onto its secrets. The USAF's recent confiscation of 1600 acres of public land bordering the facility is consistent with the Pentagon's desire to maintain its lead in quantum leap technologies -- some of which, according to well qualified observers in and around the Nevada area, defy current thinking into the predicted direction of aerospace engineering.

That aerospace ocmpanies continue to look at highly radical alternative air vehicle concepts is evidence of the ongoing quest for breakthrough designs. Glimpses into this world are rare, but provide some insight into likely 21st century research activity. The 1990 unclassified 'Electric Propulsion Study' (a quest for antigravity propulsion system by another name) conducted by the USA's Science Application International Corp (SAIC) on behalf of USAF's then Astronautics Laboratory at Edwards AFB shows that USAF visionaries are still being given free reign. Until recently BAe (British Aerospace) also provided internal resources for its own anti-gravity studies and even went so far as to outline this thinking with artists' concepts -- a case of Lawrence Bell's vision perhaps being not so wide of the mark after all.

Before he died, Ben Rich, who headed Lockheed's Skunk Works from 1975-1991, was quoted as saying: "We have some new things. We are not stagnating. What we are doing is updating ourselves, without advertising. There are some new programmes, and there are certain things -- some of them 20 to 30 years old -- that are still breakthroughs and appropriate to keep quiet about. Other people don't have them yet.

Thirty years from now, we may still not know the half of what is currently being tested in and around Groom Lake.

AUTHOR(s): McIntosh, C.B.G. Arianrhod, R. Wade, S.
TITLE(s): Electric and magnetic Weyl tensors: classification
and analysis.
In: Classical and quantum gravity.
JUN 01 1994 v 11 n 6 Page 1555

AUTHOR(s): Arianrhod, R. Lun, A.W.-C. McIntosh, C.B.G.
TITLE(s): Magnetic curvatures.
In: Classical and quantum gravity.
SEP 01 1994 v 11 n 9 Page 2331

AUTHOR(s): Arianrhod, R. McInthosh, C.B.G.
TITLE(s): Principle null directions of Petrov type I Weyl spinors:
geometry and symmetry.
In: Classical and quantum gravity.
AUG 01 1992 v 9 n 8 Page 1969

AUTHOR(s): Hoenselaers, C. Perjes, Z.
TITLE(s): Multipole moments of axisymmetric electrovacuum spacetimes.
In: Classical and quantum gravity.
OCT 01 1990 v 7 n 10 Page 1819

AUTHOR(s): de Felice, Fernando Yu, Yunqiang Fang, Jing
TITLE(s): Relativistic charged spheres.
In: Monthly notices of the royal astronomical societ NOV 01 1995 v 277 n 1 Page: L17

AUTHOR(s): de Felice, Fernando
TITLE(s): Dynamics on a rotating disk.
In: Physical review. A, Atomic, molecular, and opt NOV 01 1995 v 52 n 5 Page 3452

AUTHOR(s): de Felice, Fernando Yu, Yunqiang Coriasco, Sandro
TITLE(s): The Lynden-Bell and Katz Definition of Gravitational
Energy: Applications to Singular Solutions. In: General relativity and gravitation.
AUG 01 1994 v 26 n 8 Page 813

AUTHOR(s): Cavaglia, Marco de Alfaro, Vittorio de Felice, Fernando
TITLE(s): Anisotropic wormhole: Tunneling in time and space.
In: Physical review d: particles, fields, gravitat JUN 15 1994 v 49 n 12 Page 6493

AUTHOR(s): de Felice, Fernando
TITLE(s): Rotating frames and measurements of forces in general
relativity.
In: Monthly notices of the royal astronomical societ SEP 15 1991 v 252 n 2 Page 197

AUTHOR(s): Hammond, Richard
TITLE(s): Tetrad Formulation of Gravity with a Torsion Potential.
In: General relativity and gravitation.
NOV 01 1994 v 26 n 11 Page 1107

AUTHOR(s): Hammond, Richard
TITLE(s): Spin, Torsion, Forces.
In: General relativity and gravitation.
MAR 01 1994 v 26 n 3 Page 247

AUTHOR(s): Hammond, Richard T.
TITLE(s): Gauge Invariant Electromagnetic Coupling with Torsion Potential.
In: General relativity and gravitation.
NOV 01 1991 v 23 n 11 Page 1195

AUTHOR(s): Hammond, Richard T.
TITLE(s): Magnetic Charge Type Equations from Torsion.
In: General relativity and gravitation.
SEP 01 1991 v 23 n 9 Page 973

AUTHOR(s): Hammond, Richard T.
TITLE(s): Dynamic Torsion from a Linear Langrangian.
In: General relativity and gravitation.
APR 01 1990 v 22 n 4 Page 451

AUTHOR(s): Ringermacher, H.I.
TITLE(s): An electrodynamic connection.
In: Classical and quantum gravity.
SEP 01 1994 v 11 n 9 Page 2383

AUTHOR(s): Anandan,J. Hagen, C.R.
TITLE(s): Neutron acceleration in uniform electromagnetic fields.
In: Physical review. A, Atomic, molecular, and opt OCT 01 1994 v 50 n 4 Page 2860

AUTHOR(s): Anandan, J.
TITLE(s): Relativistic gravitation and superconductors.
In: Classical and quantum gravity.
JUN 01 1994 v 11 n 6A Page 23

AUTHOR(s): Georgiou, A.
TITLE(s): Rotating Einstein-Mazwell fields: smoothly matched
exterior and interior spacetimes with charged dust and surface layer.
In: Classical and quantum gravity.
JAN 01 1994 v 11 n 1 Page 167

AUTHOR(s): Unnikrishnan, C.S.
TITLE(s): Experimental gravitation in India: progress and challenges.
In: Classical and quantum gravity.
JUN 01 1994 v 11 n 6A Page 195

AUTHOR(s): Cowsik, R. Tandon, S.N. Unnikrishnan, C.S.
TITLE(s): Limit on the strength of intermediate-range forces coupling
to isospin.
In: Physical review letters.
NOV 07 1988 v 61 n 19 Page 2179

AUTHOR(s): Banerjee, A. Panigrahi, D. Chatterjee, S.
TITLE(s): Evolution of Kaluza-Klein inhomogeneous model with a
cosmological constant.
In: Journal of mathematical physics.
JUL 01 1995 v 36 n 7 Page 3619

AUTHOR(s): Chatterjee, S. Panigrahi, D. Banerjee, A.
TITLE(s): Inhomogeneous Kaluza-Klein cosmology.
In: Classical and quantum gravity.
FEB 01 1994 v 11 n 2 Page 371

It might interest antigravity researchers to know (for those not already aware) that Professor ER Laithwaite, a respected British electrical engineer, has been doing work on this very subject for decades, but when he tried to demonstrate the viability of his theories to his peers their closed minds closed ranks and ridiculed his efforts as fantasy. Laithwaite lost cred with the scientific community and had to rely just on one or two close associates in semi-secrecy.

A recent (a year or two ago) series of TV programmes in Britain (on controversial scientific discoveries that have yet to accepted by the scientific establishment as worthy of further research and funding) ran an episode on Laithwaite. He claimed that gyroscopes could transfer mass.

I know of one book he wrote: Transport Without Wheels published by Paul Elek in 1977 ISBN 0236400665 (info from an old note I made) though this is NOT specifically about his antigravity theories (I remember that it concentrated on propulsion via electrical rails)

I would be most interested in learning about anything he (or anyone else) might have written specifically on his antigravity work.
- George Szaszvari

"Propulsion by Gyro", Eric Laithwaite, Space, Sep 1989 Vol 5 No 5 In an attempt to reveal the strange, hidden properties of gyroscopes, Professor Eric Laithwaite explains the physics behind the idea that a propulsion system could be built using gyros. -------------------------------
-

RS Electrogravitic References: Part 16 of 19. AUTHOR(s): Ljubicic, A. Zovko, N.
TITLE(s): Lorentzian component of the fifth force.
In: Fizika B.
JAN 01 1992 v 1 n 1 Page: 1

AUTHOR(s): Bertotti, B. Sivaram, C.
TITLE(s): Radiation of the <> field.
In: Il Nuovo cimento della Societa italiana di fisic NOV 01 1991 v 106 n 11 Page: 1299

AUTHOR(s): Fujii, Y.
TITLE(s): The Theoretical Background of the Fifth Force.
In: International journal of modern physics. a, pa AUG 20 1991 v 6 n 20 Page: 3505

AUTHOR(s): Mannheim, Philip D.
TITLE(s): General Relativity and Fifth Force Experiments.
In: Astrophysics and space science.
JUL 01 1991 v 181 n 1 Page: 55

AUTHOR(s): Cho, Y.M. Park, D.H.
TITLE(s): Fifth Force from Kaluza-Klein Unification.
In: General relativity and gravitation.
JUL 01 1991 v 23 n 7 Page: 741

AUTHOR(s): Fujii, Y.
TITLE(s): Locally varying particle masses due to a scalar fifth-force field.
In: Physics letters: [Part B]
FEB 14 1991 v 255 n 3 Page: 439

AUTHOR(s): Hagiwara, Yukio
TITLE(s): No gravimetric evidence for the fifth force?
Summary: TEXT IN JAPANESE
In: Chigaku zasshi =
1991 v 100 n 3 Page: 429

AUTHOR(s): Cho, Y.M. Park, D.H.
TITLE(s): Higher-dimensional unification and fifth force.
In: Il nuovo cimento delle societa italiana di fisic AUG 01 1990 v 105 n 8/9 Page: 817

AUTHOR(s): Sardanashvily, G.
TITLE(s): The Gauge Model of the Fifth Force (E,SUM).
In: Acta physica Polonica, B.
AUG 01 1990 v 21 n 8 Page: 583

AUTHOR(s): Schimdt, H.-J.
TITLE(s): Fifth force, dark matter, and fourth-order gravity.
In: Europhysics letters.
AUG 01 1990 v 12 n 7 Page: 667

AUTHOR(s): de Sabbata, Venzo Sivaram, C.
TITLE(s): Fifth Force as a Manifestation of Torsion.
In: International journal of theoretical physics.
JAN 01 1990 v 29 n 1 Page: 1

AUTHOR(s): Timoshenko, E.G. Sardanashvily, G.A.
TITLE(s): Gauge model for the fifth force.
In: Moscow university physics bulletin.
1990 v 45 n 4 Page: 73

AUTHOR(s): Hagiwara, Yukio
TITLE(s): The fifth force-doubt about newton's gravitational law
Summary: TEXT IN JAPANESE
In: Chigaku zasshi =
1990 v 99 n 3 n 904 Page: 263

AUTHOR(s): Gasperini, M.
TITLE(s): Phenomenological consequences of a direct fifth force coupling to photons.

In: Physical review. D, Particles and fields. NOV 15 1989 v 40 n 10 Page: 3525

AUTHOR(s): Gasperini, M.
TITLE(s): Fifth force and the gravi-magnetic hypothesis..
In: Physics letters: [part A]
OCT 02 1989 v 140 n 6 Page: 271

AUTHOR(s): Fayet, P.
TITLE(s): The fifth force charge as a linear combination of baryonic,
leptonic (or B-L) and electric charges.
In: Physics letters: [Part B]
AUG 17 1989 v 227 n 1 Page: 127

AUTHOR(s): Mufti, A. Kwong, N.H. Schaudt, K.J.
TITLE(s): Search for the fifth force using Gauss's law.
In: Physics letters: [part A]
JUL 31 1989 v 139 n 3 / 4 Page: 115

AUTHOR(s): Bizzeti, P.G.
TITLE(s): Search for a Composition-Dependent Fifth Force.
Summary: A differential accelerometer consisting of a solid sphere
floating freely inside a stratified saline solution has been used to search for a composition-dependent force, originated by a mountain relief. No evidence of such a force has been obtained.
In: Physical review letters.
JUN 19 1989 v 62 n 25 Page: 2901

AUTHOR(s): T.M. Aliev, Dobroliubov, M.I. Ignatiev, A. Yu.
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In: Physics letters: [Part B]
APR 20 1989 v 221 n 1 Page: 77

AUTHOR(s): Riveros, C. Logiudice, E. A. Vucetich, H.
TITLE(s): On differential fifth force measurements.
In: Physics letters: [part A]
APR 17 1989 v 136 n 7/8 Page: 343

AUTHOR(s): Kuroda, K. Mio, N.
TITLE(s): A Free Fall Interferometer to Search for a Possible Fifth
Force.
In: IEEE transactions on instrumentation and measure APR 01 1989 v 38 n 2 Page: 189

AUTHOR(s): Faller, J. E. Fischbach, E. Fujii, Y.
TITLE(s): Precision Experiments to Search for the Fifth Force.
In: IEEE transactions on instrumentation and measure APR 01 1989 v 38 n 2 Page: 180

AUTHOR(s): Stubbs, C. W. Adelberger, E. G. Heckel, B. R.
TITLE(s): Gravitation and Astrophysics: Limits on
composition-dependent interactions using a laboratory source: Is there a "fifth force" coupled to isospin? In: Physical review letters.
FEB 06 1989 v 62 n 6 Page: 609

TITLE(s): Alternate source of fifth force challenged.
In: Science news.
OCT 01 1988 v 134 n 14 Page: 214

TITLE(s): The stimulation of the fifth force.
In: Nature.
SEP 29 1988 v 335 n 6189 Page: 393

One of the first "scientific" DOGMAS fed to new physics students is the doctrine about "projectile motion". Students are given several formulas or equations from which they can precisely calculate how high and far a projectile will travel given its initial speed and angle from the ground. But the results are NOT so absolute as students are led to believe, even if they take into account air resistance and Coriolis effects.
Recent experiments have shown that if the projectile is SPINNING at HIGH SPEED, (at least 27,000 RPM), [axis of spin coinciding with line of projection], the projectile will travel HIGHER and FARTHER than predicted by Newtonian mechanics! Similarly, experiments with falling gyroscopes have

shown that a gyroscope whose enclosed rotor is spinning at high speed (about 27,000 RPM) falls AT A DIFFERENT RATE than when the same gyroscope falls with rotor NOT spinning. The AMOUNT of DEVIATION might depend on the MATERIAL COMPOSITION of the projectile or rotor, as suggested in the text of U.S. Patent #3,626,605, "Method and Apparatus for Generating a Secondary Gravitational Force Field", by Henry W. Wallace, Dec. 14, 1971.
These DEVIATIONS are EASILY REPRODUCABLE, and effectively DIS-PROVE the OVER-
HYPED "General Theory of Relativity" which states that gravity results from a "warping or distorion of space" caused by the MERE PRESENCE of mass. - Robert McElwaine
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The late Henry W Wallace died april 1994. Fellow researchers at GE were not "happy" with his research regarding gravitational fields. An interesting article was written in The New Scientist circa 1980 about Wallace's work.
-- Ron Kita

Henry Wallace was an engineer at General Electric about 25 years ago, and developed some incredible inventions relating to the underlying physics of the gravitational field. Few people have heard of him or his work.

US Patent #3626605 -- "Method and Apparauts for Generating a Secondary Gravitational Force Field"
Awarded to Henry Wm Wallace of Ardmore PA Dec 14, 1971

US Patent #3626606 -- "Method and Apparatus for Generating a Dynamic Force Field"
Awarded to Henry Wm Wallace of Ardmore PA Dec 14, 1971

US Patent #3823570 -- "Heat Pump" (based on technology similar to the above two inventions)
Awarded to Henry Wm Wallace of Freeport NY July 16, 1973

Wallace discovered that a force field, similar or related to the gravitational field, results from the interaction of relatively moving masses. He built machines which demonstrated that this field could be generated by spinning masses of elemental material having an odd number of nucleotides -- i.e. a nucleus having a multiple half-integral value of h-bar, the quantum of angular momentum. Wallace used bismuth or copper material for his rotating bodies and "kinnemassic" field concentrators. Aside from the immense benefits to humanity which could result from a better understanding of the physical nature of gravity, and other fundamental forces, Wallace's inventions could have enormous practical value in countering gravity or converting gravitational force fields into energy for doing useful work. So, why has no one heard of him? One might think that the discoverer of important knowledge such as this would be heralded as a great scientist and nominated for dynamite prizes. Could it be that his invention does not work? Anyone can get the patents. Study them -- Wallace -- General Electric -- detailed descriptions of operations -- measurements of effects -- drawings and models -- it is authentic. If you're handy you can even build it yourself. It does work.

So what is going on?
One explanation I've heard is that Wallace ran up against the politics of science, as dictated in the late 1960's by the power-block at Princeton, who were primarily interested in promoting the ideas of their main man, Einstein, and the gravitation-is-geometry paradigm. Maybe there is some truth to this story. Nowadays, there seems to be a piss-pot full of theoretical physicists working on abstract geometrical theories and other absurdly difficult mental masturbations, while no one seems to have made any effort to provide a theoretical explanation of the physics of a nuts-and-bolts invention which could have enormous practical value. Maybe we can blame it on the Princeton folks, but I'm more inclined to believe that our defense industry black project community has confiscated and

suppressed knowledge of Wallace's discoveries. All done of course under the most honorable and sacred banner of national security. Well, it's been 25 years. We ought to be real secure by now. Isn't it way past time for some trickle down benefits to real people? ---
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There are two paragraphs about the Wallace inventions in the Electric Propulsion Study by Dr Dennis Cravens, prepared in 1991. Cravens had this to say about Wallace's work:

ROTATIONAL ALIGNMENT - Nuclei can also be aligned by rotation. Henry Wallace claimed some unusual effects assigned to electomagnetic and gravitational couplings. This was in three US patents (3823570, 3626605, and 362606). The assertion was that the application of a rotational force on a material of half-integral spin would result in a reorientation of the nuclear structure and could be utilized for "altering its gravitational attraction toward other bodies, separation of isotopes by distinguishing between nuclei according to their nucleon content..." The patents are written in a very believable style which includes part numbers, sources for some components, and diagrams of data.

Attempts were made to contact Wallace using patent addresses and other sources but he was not located nor is there a trace of what became of his work. However, should the work be real it may furnish a novel experimental approach to experimental design. The concept can be somewhat justified on general relativistic grounds since rotating frames of time varying fields are expected to emit gravitational radiation. Even if the work does not give a direct gravitational coupling it may furnish a new method for nuclear spin alignment.

An article about the Wallace patents appeared in the British magazine "New Scientist" in February 1980. This was written nearly ten years after Wallace was awarded his patents. Here's a paragraph from the article.

"Although the Wallace patents were initially ignored as cranky, observers believe that his invention is now under serious but secret investigation by the military authorities in the US. The military may now regret that the patents have already been granted and so are available for anyone to read."

I know -- it's a tease. And the rest of the article is the same way. It provides barely enough information to jab your psyche a little, and not nearly enough to get you off your comfortable ass. And who knows who the anonymous party of "observers" are, who believe that a secret investigation is underway by the military -- or whether these observers even exist at all. None the less, the New Scientist has a fairly well established track record for accurate identification of new science trends and issues. And, while the editors of this British journal may be prone to enjoyment of gossip and innuendo, it generally turns out be grounded in truth. -----------------------
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NUCLEAR SPIN SELECTIVITY OF CHEMICAL REACTIONS A.L.Buchachenko, N.N.Semenov Institute of Chemical Physics, Russian Academy of Sciences
4 Ul. Kosygina, 117334 Moscow, Russian Federation, Fax: +7(095)938-2156 A property of spin selective reactions to sort the nuclei according to their spin and orientation, is discussed. The separation of spin (magnetic) and spinless (nonmagnetic) nuclei forms the basis for the magnetic isotope effect, the separation of nuclei according to their orientation and creation of nuclear alignment in reaction products is a basis for the chemically induced nuclear polarisation phenomenon. Bibliography - 50 references.
Received 14 February 1995

NUCLEAR THEORY, ABSTRACT NUCL-TH/9601046 From: spevak@TAUPHY.TAU.AC.IL
Date: Tue, 30 Jan 1996 17:18:34 +0200

Collective T- and P- Odd Electromagnetic Moments in Nuclei with Octupole Deformations
Author(s): N. Auerbach , V.V. Flambaum , V. Spevak Parity and time invariance violating forces produce collective P- and T- odd moments in nuclei with static octupole deformation. Collective Schiff moment, electric octupole and dipole and also magnetic quadrupole appear due to the mixing of rotational levels of opposite parity and can exceed single-particle moments by more than a factor of 100. This enhancement is due to two factors, the collective nature of the intrinsic moments and the small energy separation between members of parity doublets. The above moments induce T- and P- odd effects in atoms and molecules. Experiments with such systems may improve substantially the limits on time reversal violation.

The Hughes-Drever experiment was conducted in 1959-1960 independently by Vernon Hughes and collaborators at Yale University, and by Ron Drever at Glasgow University. In the Glasgow version, the experiment examined the ground state of the lithium-7 nucleus in an external magnetic field. The state has total angular momentum quantum number 3/2, and thus is spolit into four equally spaced levels by the magnetic field. When the nucleus undergoes a transition between a pair of adjacent levels, the photon emitted has the same energy or frequency, no matter which pair of levels was involved. The result is a single narrow spectral line. Any external perturbation of the nucleus that is associated with a preferred direction in space, such as the motion of the Earth relative to the mean rest frame of the universe, will destroy the equality of the energy spacing between the four levels, since the nuclear wave functions of the four levels have different spacial dependencies relative to the magnetic field. Using nuclear magnetic resonance techniques, the experiments set a limit on the separation or spread in frequency of line that corresponded to a limit on anistropy or bidirectional dependence in the energy of the nucleu at the level of one part in 10^23. -- Clifford Will, Chapt 2 of The New Physics, edited by Paul Davies --

Magnetic resonance in its various forms, NMR, EPR, and EFR, are all applied to relatively small specimens and, with the exception of EFR, are rarely applied to magnetic materials. EFR means Electron Ferromagnetic Resonance, and the best intro to this subject is by Vonsovskii. Curiously, there is no published data on EFR for large ferromagnetic specimens. A literature search at a campus of the University of California revealed nothing. F. Herlach has said that there is an 'open' literature and a 'closed' literature concerning magnetic research.
-- Larry Adams

A body which is spinning within a larger macroscopic body which is also spinning will tend to align the axis of its angular momentum with the angular momentum of the larger body.

For example, a gyroscope located on the earth, unless it is in a frictionless gimbal, with always try to precess due to the rotation of the earth into alignment with the earth's polar axis, at which point it will no longer precess due to earth rotation.
Another example, a cylinder of magnetic material spinning around its longitudinal axis will develop a magnetic field proportional to is angular velocity (Barnett Effect), because the angular momemtum of the electrons in the material will attempt to precess and come into alignment with the macroscopic axis of the spinning cylinder, which also brings into alignment the magnetic moment of the electrons, some of which have unpaired spins (ferromagnetic), resulting in generation of a macroscopic magnetic field. Similarly, it is know that a static magnetic field itself contains angular momentum -- and spinning the source of the static field, whether a magnet or DC current loop, will result in a corresponding increase or decrease in the field strength.

Another example is the inventions of Henry Wallace. Wallace found that if you spin a

material which has an odd number of nucleotides, i.e. having an "un-
paired" value of angular momentum, resulting in a nucleus with a multiple integer of a one-half value of quantum momentum. The spin in the nucleus will begin to line up with the macroscopic spin axis, and will create an unusual force field related to gravity -- which he call a "kinemassic" field.

Maybe I've missed it, but I've looked seriously, and there seems to be no information in undergraduate or graduate level physics reference books which mentions the relationship between macroscopic and microscopic angular momentum -- much less provides any analysis or explanation linking quantum angular momentum to macroscopic angular momentum. Why not? How does quantum angular momentum become organized from a microscopic to a macroscopic level? Has anyone ever published any work about this? I can't find any.

Date: Sun, 5 Nov 1995
From: James Youlton To: Robert Stirniman
Re: Angular Momentum and the Barnett Effect

On Wed, 1 Nov 1995, Robert Stirniman wrote:
>Maybe I've missed it, but I've looked seriously, and there seems to be no information in undergraduate or graduate level physics reference books which mentions the relationship between macroscopic and microscopic angular momentum -- much less provides any analysis or explanation linking quantum angular momentum to macroscopic angular momentum.

You're catching on. The subject of compound angular momentum, or internal and external angular momentum, or intrinsic and extrinsic angular momentum has been a repressed subject for about 2 and half decades. Add to that list, spherical pendulums, Coriolis effect, except as applied to balistics and meteorology as used by the US military, and Shafer's pendulum, that neat little device used as the artifical horizon of aircraft.

>How does quantum angular momentum become organized from a microscopic to a macroscopic level? Has anyone ever published any work about this? I can't find any.

There isn't any that I know of, though back in the late fifties, there was a fellow named Edward Condon at the University of Colorado who was fairly proficient on the subject. So much so that he wrote the rotational dynamics section, called noninertial dynamics at the time, of the reference "The Handbook of Physics" which he also co-edited (Chapter 5). I don't recall offhand who the publisher was (Harcourt/Brace?), though it was endorsed by the American Institute of Physics. Later, when Mr Condon was the head of the USAF project 'Blue Book', he labored to supress his own work when the directive was handed down from the Navy's Turtle Island project.
-- James Youlton

Condon directed a government UFO project, but was never the head of Blue Book. That position was held, for most or perhaps all of Blue Book's life, by an Air Force Officer Named Edward Ruppelt. Blue Book was shut down in 1969, shortly after the report of the project Condon directed, "Scientific Study of Unidentified Flying Objects". -- Jim Giglio
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AUTHOR: Cousins, Frank W.
TITLE: The anatomy of the gyroscope : a report in 3 parts comprising
a literature and patent survey directed to the gyroscope and its applications / by Frank W. Cousins ; edited by John L. Hollington.
PUBL.: Neuilly-sur-Seine, France : North Atlantic Treaty
Organization, Advisory Group for Aerospace Research and Development,
FORMAT: 296 p. (in various pagings) ; 30 cm.
DATE: 1988
SERIES: AGARDograph no. 313

AUTHOR: Leimanis, E. (Eugene)
TITLE: The general problem of the motion of coupled rigid bodies

about a fixed point.
PUBL.: Berlin, New York, Springer-Verlag,
FORMAT: xvi, 337 p. illus. 24 cm.
DATE: 1965
SERIES: Springer tracts in natural philosophy. v. 7
SUBJECT Dynamics, Rigid Gyroscopes, Two-body problem, Astrodynamics

AUTHOR(s): de Andrade, L.C. Garcia
TITLE: Electron gyroscopes to test torsion gravity?
In: Il nuovo cimento delle societa italiana di fisic OCT 01 1994 v 109 n 10 Page 1123

AUTHOR(s): Abe, Hiroshi Yoshida, Tetsuo Turuga, Kikuo
TITLE: Piezoelectric-ceramic cylinder vibratory gyroscope.
In: Japanese journal of applied physics. part 1, r SEP 01 1992 v 31 n 9B Page 3061

AUTHOR(s): Case, William B. Shay, Michael A.
TITLE: On the interesting behavior of a gimbal-mounted gyroscope.
In: American journal of physics.
JUN 01 1992 v 60 n 6 Page 503

AUTHOR(s): Zhuravlev, V.F.
TITLE: Nutational self-oscillation of a free gyroscope.
In: Mechanics of solids.
1992 v 27 n 6 Page 11

AUTHOR(s): Chang, C.O. Chou, C.S.
TITLE: Partially Filled Nutation Damper for a Freely Processing
Gyroscope.
In: Journal of guidance, control, and dynamics.
SEP 01 1991 v 14 n 5 Page 1046

AUTHOR(s): Chang, C.O. Chou, C.S. Liu, L.Z.
TITLE: Stability analysis of a freely precessing gyroscope
carrying a mercury ring damper.
In: Journal of sound and vibration.
MAY 08 1991 v 146 n 3 Page 491

AUTHOR(s): Imanishi, Akira Maruyama, Koichi Midorikawa, Shoichi
TITLE: Observation against the Weight Reduction of Spinning
Gyroscopes.
In: Journal of the physical society of japan. APR 01 1991 v 60 n 4 Page 1150

AUTHOR(s): Petry, Walter
TITLE: Angular Momentum and Gyroscope in Flat Space-Time Theory of
Gravitation.
In: Astrophysics and space science.
JAN 01 1991 v 175 n 1 Page 1

AUTHOR(s): Zhivkov, A.I.
TITLE: Geometry of invariant manifolds of a gyroscope in the field
of a quadratic potential.
In: Mathematics of the USSR: Izvestija.
1991 v 37 n 1 Page 227

AUTHOR(s): Hayashi, Kenji Shirafuji, Takeshi
TITLE: Frame-Dragging Precession of Orbiting Gyroscopes in New
General Relativity and Possible Violation of Equivalence Principle.
In: Progress of theoretical physics.
DEC 01 1990 v 84 n 6 Page 1074

AUTHOR(s): El-Sabaa, F.M.
TITLE: On the Periodic Motion of a Gyroscope Supported by Cardan
Gimbals.
In: al-Majallah al-Arabiyah lil-ulum wa-al-handasa JUL 01 1990 v 15 n 3 Page 495

AUTHOR(s): Moffat, J.W. Brownstein, J.R.
TITLE: Spinning test particles and the motion of a gyroscope
according to the nonsymmetric gravitation theory. In: Physical review. D, Particles and fields. MAY 15 1990 v 41 n 10 Page 3111

AUTHOR(s): Nitschke, J.M. Wilmarth, P.A.
TITLE: Null result for the weight change of a spinning gyroscope.
In: Physical review letters.
APR 30 1990 v 64 n 18 Page 2115

AUTHOR(s): Faller, J. E. Hollander, W. J. Nelson, P. G.
TITLE(s): Gyroscope-weighing experiment with a null result.
In: Physical review letters.
FEB 19 1990 v 64 n 8 Page 825

AUTHOR(s): Rumyantsev, V.V.
TITLE: Stability of permanent rotations of a nonsymmetric
liquid-filled gyroscope.
In: Mechanics of solids.
1990 v 25 n 6 Page 1

AUTHOR(s): Panayotounakos, D.E. Theocaris, P.S.
TITLE: On the Decoupling and the Solutions of the Euler Dynamic
Equations Governing the Motion of a Gyroscope. In: Zeitschrift fur angewandte Mathematik und Mechan 1990 v 70 n 11 Page 489

AUTHOR(s): Hayasaka, Hideo Takeulchi, Sakae
TITLE: Gravitation and Astrophysics.
Summary: Anomalous weight reduction on a gyroscope's right rotations
around the vertical axis on the Earth.
In: Physical review letters.
DEC 18 1989 v 63 n 25 Page 2701

AUTHOR(s): Laithwaite, Eric
TITLE: Propulsion by Gyro.
Summary: In an attempt to reveal the strange, hidden properties of
gyroscopes, Professor Eric Laithwaite explains the physics behind the idea that a propulsion system could be built using gyros.
In: Space. SEP 01 1989 v 5 n 5 Page 36

AUTHOR(s): Vitale, S. Bonaldi, M. Falferi, P.
TITLE: Magnetization by rotation and gyromagnetic gyroscopes.
Summary: We discuss how the general phenomenon of magnetization by
rotation may be used probe the angular velocity of the laboratory with respect to a local frame of inertia. We show that gyroscope with no moving parts based on this pheno-
In: Physical review B: Condensed matter. JUN 01 1989 v 39 n 16 p B Page 11993

AUTHOR(s): Aspden, H.
TITLE: Anti Gravity Electronics.
Summary: Reinterpretation of Newton's Third Law of Motion suggests
that it depends upon and electronic action. Electronic interaction therefore explains the paradoxical anti-gravity properties of the force processed gyroscope. In: Electronics & Wireless World.
JAN 01, 1989 v 95 n 1635 Page 29

AUTHOR(s): Sachs, Mendel
TITLE: The Precessional Frequency of a Gyroscope in the
Quaternionic Formulation of General Relativity. In: Foundations of physics.
JAN 01 1989 v 19 n 1 Page 105

AUTHOR(s): Medvedev, A.V.
TITLE: Motion of a rapidly run-up gyroscope acted upon by a
constant moment in a resistive medium.
In: Mechanics of solids.
1989 v 24 n 2 Page 21

AUTHOR(s): Starzhinskii, V.M.
TITLE: An exceptional case of motion of the Kovalevskaia
gyroscope.
In: PMM, Journal of applied mathematics and mechanic 1983 v 47 n 1 Page 134

AUTHOR: Gray, Andrew, 1847-1925.
TITLE: A treatise on gyrostatics and rotational motion; theory and
applications.
PUBL.: New York, Dover Publications
FORMAT: 530 p. illus. 22 cm.
DATE: 1959

QA861:P4
Perry, John
SPINNING TOPS AND GYROSCOPIC MOTION. By John Perry. Dover, 1957. 102 pages

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Articles and Books by Kip Thorne:

AUTHOR: Misner, Charles W.
TITLE: Gravitation (by) Charles W. Misner, Kip S. Thorne (and) John Archibald Wheeler.
PUBL.: San Francisco, W. H. Freeman
FORMAT: xxvi, 1279 p. illus. 26 cm. 1973
SUBJECT: Astrophysics, General relativity, Gravitation

GENERAL RELATIVITY & QUANTUM COSMOLOGY, ABSTRACT GR-QC/9308009 THE QUANTUM PROPAGATOR FOR A NONRELATIVISTIC PARTICLE IN THE VICINITY OF A TIME MACHINE DALIA S. GOLDWIRTH, MALCOLM J. PERRY, TSVI PIRAN AND KIP S.THORNE.
We study the propagator of a non-relativistic, non-interacting particle in any non-relativistic ``time-machine" spacetime of the type shown in Fig. 1: an external, flat spacetime in which two spatial regions, V- at time t- and V+ at time t+, are connected by two temporal wormholes, one leading from the past side of V- to t the future side of V+ and the other from the past side of V+ to the future side of V-. We express the propagator explicitly in terms of those for ordinary, flat spacetime and for the two wormholes; and from that expression we show that the propagator satisfies completeness and unitarity in the initial and final ``chronal regions" (regions without closed timelike curves) and its propagation from the initial region to the final region is unitary. However, within the time machine it satisfies neither completeness nor unitarity. We also give an alternative proof of initial-region-to-final-
region unitarity based on a conserved current and Gauss's theorem. This proof can be carried over without change to most any non-relativistic time-machine spacetime; it is the non-relativistic version of a theorem by Friedman, Papastamatiou and Simon, which says that for a free scalar field, quantum mechanical unitarity follows from the fact that the classical evolution preserves the Klein-Gordon inner product.

AUTHOR(s): Thorne, Kip S.
TITLE(s): Gravitational-wave bursts with memory: The Christodoulou effect.
In: Physical review. D, Particles and fields. JAN 15 1992 v 45 n 2 Page 520

AUTHOR(s): Apostolatos, Theocharis A. Thorne, Kip S.
TITLE(s): Rotation halts cylindrical, relativistic gravitational collapse.
In: Physical review. D, Particles and fields. SEP 15 1992 v 46 n 6 Page 2435

AUTHOR(s): Echeverria, Fernando Klinkhammer, Gunnar Thorne, Kip S.
TITLE(s): Billiard balls in wormhole spacetmes with closed timelike curves: Classical theory.
In: Physical review. D, Particles and fields. AUG 15 1991 v 44 n 4 Page 1077

AUTHOR(s): Eich, Chris Zimmermann, Mark E. Thorne, Kip S.
TITLE(s): Giant and supergiant stars with degenerate neutron cores.
In: The astrophysical journal.
NOV 01 1989 v 346 n 1 p 1 Page 277

AUTHOR(s): Frolov, Valery P. Thorne, Kip S.
TITLE(s): Renormalized stress-energy tensor near the horizon of a slowly evolving, rotating black hole
Summary: The renormalized expectation value of the stress-energy tensor ren of a quantum field in an arbitrary quantum state near the future horizon of a rotating (Kerr) black hole is derived in two very different ways: One derivation (restricted for simplicity to a massless scalar field) makes use of traditional techniques of quantum field theory in curved spacetime, augmented by a variant of the "ETA formalism " for handling superradiant modes. In: Physical review. D, Particles and fields. APR 15 1989 v 39 n 8 Page 2125

AUTHOR(s): Kim, Sung-Won Thorne, Kip S.

TITLE(s): Do vacuum fluctuations prevent the creation of closed
timelike curves?
In: Physical review. D, Particles and fields. JUN 15 1991 v 43 n 12 Page 3929

AUTHOR: Thorne, Kip S.
TITLE: Black holes and time warps : Einstein's outrageous legacy /
Kip S. Thorne.
PUBL.: New York : W.W. Norton,
FORMAT: 619 p. : ill. ; 24 cm. 1994
SERIES: Commonwealth Fund Book Program (Series)
SUBJECT: Relativity, Astrophysics, Physics--Philosophy, Black holes

AUTHOR: Harrison, B. Kent.
TITLE: Gravitation theory and gravitational collapse (by) B. Kent
Harrison, Kip S. Thorne, Masami Wakano (and) John Archibald Wheeler.
PUBL.: Chicago, University of Chicago Press
FORMAT: xvii, 177 p. illus. 25 cm. 1965
SUBJECT: Astrophysics, Gravitation

AUTHOR: Thorne, Kip S.
TITLE: Gravitational radiation : a new window onto the universe /
Kip S. Thorne, William R. Kenan, Jr.
PUBL.: Cambridge, (Cambridgeshire) ; New York : Cambridge University
Press,
DATE: 1988
SUBJECT: Gravitational radiation

AUTHOR: Braginskii, V. B. (Vladimir Borisovich
TITLE: Quantum measurement / Vladimir B. Braginsky and Farid Ya.
Khalili ; edited by Kip S. Thorne.
PUBL.: Cambridge (England) ; New York, NY, USA : Cambridge
University Press,
SUBJECT: Quantum theory, Physical measurements

AUTHOR: Braginskii, V. B. (Vladimir Borisovich)
Sistemy s maloi dissipatsiei. English
TITLE: Systems with small dissipation / V.B. Braginsky, V.P.
Mitrofanov, V.I. Panov ; edited by Kip S. Thorne and Cynthia Eller ; translated by Erast Gliner. PUBL.: Chicago : University of Chicago Press,
FORMAT: xii, 145 p. : ill. ; 24 cm. DATE: 1985
SUBJECT: Harmonic oscillators--Design and construction. Physical measurements
NOTES: Translation of: Sistemy s maloi dissipatsiei.
Includes index.

Title: Black holes : the membrane paradigm / edited by Kip S. Thorne, Richard H. Price, Douglas A. Macdonald. Date/Source: New Haven : Yale University Press, 1986. -----------
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V. F. Weisskopf, "On the Theory of the Electric Resistance of Metals," 11 (1), 1-12 (1943).

E. U. Condon and P. E. Condon, "Effect of Oscillations of the Case on the Rate of a Watch," 16 (1), 14-16 (1948).

G. F. Pake, "Fundamentals of Nuclear Magnetic Resonance Absorption 1," 18 (7), 438-452 (1950); "Fundamentals of Nuclear Magnetic Resonance Absorption II," 18 (8), 473-486 (1950).

J. H. Van Vleck, "Landmarks in the Theory of Magnetism," 18 (8),495-509 (1950).

Herbert Goldstein, "The Classical Motion of a Rigid Charged Body in a Magnetic Field," 19 (2), 100-109 (1951).

J. C. Slater, "The Electron Theory of Solids," 19 (6), 368-374 (1951).

L. I. Schiff, "Quantum Effects in the Radiation from Accelerated Relativistic Electrons," 20 (8), 474-478 (1952).

Kerson Huang, "On the Zitterbewegung of the Dirac Electron," 20 (8), ' 479-484 (1952).

F. Keffer, H. Kaplan, and Y. Yafet, "Spin Waves in Ferromagnetic and Antiferromagnetic Materials," 21 (4), 250-257 (1953).

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C. Kittel, "The Effective Mass of Electrons in Crystals," 22 (5), 250-252 (1954).

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E. M. Purcell, "Gravitation Torsion Balance," 25 (6), 393-394 (1957).

Leonard Eisenbud, "On the Classical Laws of Motion," 26 (3), 144- 159 (1958).

P. Morrison, "Approximate Nature of Physical Symmetrics," 26 (6), 358-368 (1958).

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R. H. Dicke, "Eotvos Experiment and the Gravitational Red Shift," 28 (4), 344-347 (1960).

Gerald Holton, "On the Origins of the Special Theory of Relativity," 28 (7), 627-636 (1960).

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P. W. Bridgman, "Significance of the Mach Principle," 29 (1), 32-36 (1961).

Robert Weinstock, "Laws of Classical Motion. What's F? What's m? What's a?" 29 (10), 698-702 (1961).

T. Gold, "The Arrow of Time," 30 (6), 403-410 (1962).

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David H. Frisch and James H. Smith, "Measurement of Relativistic Time Dilation Using u-Mesons," 31 (5), 342-355 (1963).

R. H. Dicke, "Cosmology, Mach's Principle and Relativity," 31 (7), 500- 509 (1963).

R. S. Shankland, "Michelson-Morley Experiment," 32 (1), 16-35 (1964).

Philip Morrison, "Less May Be More," 32 (6), 441-457 (1964).

A. L. Schawlow, "Measuring the Wavelength of Light with a Ruler," 33 (11), 922-923 (1965).

Arthur Komar, "Foundations of Special Relativity and the Shape of the Big Dipper," 33 (12), 1024-1027 (1965).

R. H. Romer, "Angular Momentum of Static Electromagnetic Fields," 34 (9), 772-778 (1966); "Electromagnetic Angular Momentum," 35 (5), 445-446(1967).

A. Gamba, "Physical Quantities in Different Reference Systems According to Relativity," 35 (2), 83-89 (1967).

Emerson M. Pugh and George E. Pugh, "Physical Significance of the Poynting Vector in Static Fields," 35 (2), 153-156 (1967).

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Gerald Holton, "Einstein and the 'Crucial' Experiment," 37 (10), 968-982 (1969)

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Timothy H. Boyer, "Energy and Momentum in Electromagnetic Field for Charged Particles Moving with Constant Velocities," 39 (3), 257-270 (1971).

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N. Bloembergen, "The Concept of Temperature in Magnetism," 41 (3), 325-331 (1973).

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Julian Schwinger, "Spin-Precession -- A Dynamical Discussion," 42 (6), 510-513 (1974).

Allan Franklin, "Principle of inertia in the Middle Ages," 44 (6), 529-545 (1976).

Hans C. Ohanian, "What is the principle of equivalence?" 45 (10), 903-909 (1977).

Frederik J. Belinfante, "Can individual elementary particles have individual properties?" 46 (4), 329-336 (1978).

Timothy H. Boyar, "Electrostatic potential energy leading to an inertial mass change for a system of two point charges," 46 (4), 383-385 (1978).

E. J. Konopioski, "What the electromagnetic vector potential describes," 46 (5), 499-502 (1978).

Sidney D. Drell, "When is a particle?" 46 (6), 597-606 (1978).

Timothy H. Boyer, "Electrostatic potential energy leading to a gravitational mass change for a system of two point charges," 47 (2), 129-131(1979).

Barry R. Holstein and Arthur R. Swift, "Elementary derivation of the radiation field from an accelerated charge," 49 (4), 346-347 (1981).

P. C. Peters, "Where is the energy stored in a gravitational field?" 49(6), 564-569 (1981).

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H. Richard Crane, "Short Foucault pendulum. A way to eliminate the precesson due to ellipticity," 49 (11), 1004-1006 (1981).

M. Danos, "Bohm-Aharonov effect. The quantum mechanics of the electrical transformer," 50 (1), 64-66 (1982).

Frank S. Crawford, "Elementary derivation of the magnetic flux quantum," 50 (6), 514-516 (1982).

Robert Weinstock, "Dismantling a centuries-old myth: Newton's Principia and inverse-square orbits," 50 (7), 610-617 (1982).

Frank S. Crawford, "Superball and time-reversal invariance," 50 (9), 856 (1982).

Robert C. Hilborn, "Einstein coefficients, cross sections, f values, dipole moments, and all that," 50 (11). 982-986 (1982).

Allen I. Janis, "Simultaneity and special relativistic kinematics," 51 (3), 209-2l3 (1983).

Hans C. Ohanian, "On the approach to electro- and magnetostatic equilibrium," 51 (11), 1020-1022 (1983).

N. David Mermin, "Relativity without light," 52 (2), 119-124 (1984).

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Victor F. Weisskopf, "Search for Simplicity: Maxwell, Rayleigh, and Mt. Everest," 54 (1), 13-14 (1986).

M. W. P. Strandberg, "Special relativity completed: The source of some 2s in the magnitude of physical phenomena," 54 (4), 321-331 (1986).

Hans C. Ohanian, "What is spin?" 54 (6), 500-505 (1986).

L. Lederman, "Unification, grand unification, and the unity of physics," 54 (7), 594-600 (1986).

E. T. Osypowski and M. G. Olason, "lsynchronous motion in classical mechanics," 55 (8), 720-725 (1987).

W. M. Saslow, "Electromechanical implications of Faraday's law: A problem collection," 55 (11), 986-993 (1987).

Michael S. Morris and Kip S. Thorne, "Wormholes in spacetime and their use for interstellar travel: A tool for teaching general relativity," 56 (5), 395-412 (1988).

Mark A. Heald, "Energy flow in circuits with Faraday emf," 56 (6), 540-547 (1988).

N. David Mermin, "The amazing many colored relativity engine," 56 (7), 600-6l1 (1988).

Timothy H. Bayer, "The force on a magnetic dipole," 56 (8), 688-692 (1988).

A. R. Janah, T. Padmanabhan, and T. P. Singh, "On Feynman's formula for the electromagnetic field of an arbitrarily moving charge," 56 (11), 1036-1038 (1988).

Harold S. Zapolsky, "On electric fields produced by steady currents," 56 (12), 1137-1141 (1988).

M. Kugler, "Motion in noninertial systems: theory and demonstrations," 57 (3), 247-251 (1989).

W. Zimmermann, Jr., "A wave-packet description of the motion of a charged particle in a uniform magnetic field," 57 (7), 593-598 (1989).

Ray Skinner and John A. Weil, "An introduction to generalized functions and their application to static electromagnetic point dipoles, including hyperfine interactions," 57 (9), 777-791 (1989).

S. Washburn, "Conductance fluctuations in loops of gold," 57 (12) 1069-1078 (1989).

Hans Dehmelt, "Less is more. Experiments with an individual atomic particle at rest in free space," 58 (1), 17-27 (1990).

Robert J. Birgenau, "Novel magnetic phenomena and high-temperature superconductivity in lamellar copper oxides," 58 (1), 28-4O (1990).

Freeman J. Dyson, "Feynman's proof of the Maxwell equations," 58 (3), 209-211(1990). See also comments by Norman Dombey, Robert W. Brehme, James L. Anderson, and I. E. Farquhar, 59(l), 85-87 (1991).

Cyrus S. MacLatchy and Hugh A. Chipman, "A dynamic method of measuring the charge induced on a conductor," 58 (9), 811-816 (1990).

G. Matteucci, "Electron wavelike behavior: A historical and experimental introduction," 58(12), 1143-1147 (1990). -------------------------------------

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SELECTED ARTICLES FROM APEIRON MAGAZINE.

Apeiron Magazine (apeiron@aei.ca)
4405 St-Dominique
Montreal, Quebec H2W 2B2 Canada.

Apeiron Number 1 (September 1987)
* Henrik Broberg (Stockholm) – Particle Mass in a Cosmological Perspective
* Toivo Jaakkola (University of Helsinki Observatory) – Mach s Principle and Properties of Local Structure

Apeiron Number 2 (February 1988)
* Jean-Claude Pecker/Jean-Pierre Vigier (University of Paris) – A Possible Tired-Light Mechanism

Apeiron Number 3 (August 1988)
* D.F. Roscoe (University of Sheffield) – Gravitation as an Inertial Process
* Amitabha Ghosh (Indian Institute of Technology, Kanpur) – Velocity-Dependent Inertial Induction: A Case for Experimental Observation

Apeiron Number 5 (Fall 1989)
* S.V.M. Clube (University of Oxford) – Lorentzian Gravity and Cosmology

Apeiron Number 8 (Autumn 1990)
* Jacques Trempe (Montreal, Quebec) – Laws of Light Propagation in Galilean Space-Time
* Thomas E. Phipps Jr. (Urbana, Illinois) – Weber-type Laws of Action-at-a-Distance in Modern Physics

Apeiron Numbers 9-10 (Winter-Spring 1991) * S.V.M. Clube (Astrophysics Department, Oxford University) – Mass Inflation as a Recurring Property of Matter in Astrophysical Situations
* Amitabha Ghosh (Indian Institute of Technology, Kanpur) – Velocity Dependent Inertial Induction: A Possible Tired-Light Mechanism * David Roscoe (Department of Applied Mathematics, Sheffield University) – Gravity out of Inertia
* Henrik Broberg (Djursholm, Sweden) – Mass, Energy, Space * Toivo Jaakkola (University Observatory, Helsinki) – Electrogravitational Coupling: Empirical and Theoretical Arguments

Apeiron Number 12 (February 1992)

* Zaman Akil (Kuwait City) – On the Constant of Gravitation * Andrй K.T. Assis (State University of Campinas, Brazil) – On Hubble's Law of Redshift, Olbers' Paradox and the Cosmic Background Radiation
* S.C. Tiwari (Banaras Hindu University, Varanasi, India) – The Nature of Time

Apeiron Number 13 (June 1992)
* Andrй K.T. Assis (State University of Campinas, Brazil) – On the Absorption of Gravity
* D.F. Roscoe (University of Sheffield) – The Equivalence Principle as a Consequence of the Third Law
* Joop F. Nieland (Arles sur Tech, France) – Vacuum Refraction Theory of Gravitation
* H.E. Wilhelm (University of Utah) – Explanation of Anomalous Unipolar Induction in Corotating Conductor-Magnet Arrangements by Galilean Electrodynamics

Apeiron Number 14 (September 1992)
* Thomas E. Phipps Jr. (Urbana, Illinois) – Lorentz Contraction of the Coulomb Field: An Experimental Proposal * Peter Huber (Germanistisches Seminar, Heidelberg University) – Does the Velocity of Light Decrease?

Apeiron Number 15 (February 1993)
* H.E. Wilhelm (University of Utah) – Galilei Covariant Electrodynamics of Moving Media with Applictions to the Experiments of Fizeau and Hoek
* S.X.K. Howusu (University of Jos, Nigeria) – The Confrontation between Relativity and the Principle of Reciprocal Action * Henrik Broberg (Norwegian Telecom, Oslo) – On the Kinetic Origin of Mass

Aperion Number 16 (June 1993)
* C.I. Mocanu (Polytechnical Institute of Bucharest, Romania) – Is Thomas Rotation a Paradox?
* Zu Shaozhi and Xu Xiangqun (Beijing Control Device Research Institute) – On the Relativity of Simultaneity * Martin Kokus (Hopewell, PA) and A.O. Barut, University of Colorado) – Suggestion for Unifying Two Types of Quantized Redshift of Astronomical Bodies

Apeiron Number 17 (October 1993)
* Thomas E. Phipps Jr. (Urbana, Illinois) – Ampere Tension and Newton's Laws
* S.X.K. Howusu (University of Jos, Nigeria) – General Mechanics of a Photon in the Gravitational Field of a Stationary Homogeneous Spherical Body

Apeiron Number 18 (February 1994)
* Toivo Jaakkola (Tuorla Observatory, Turku, Finland) – Radiative and Dynamical Implications of Electrogravity * Peter Huber (Heidelberg University) – The Cosmological Redshift as a Virtual Effect of Gravitation
* H.E. Wilhelm (University of Utah) – Fitzgerald Contraction, Larmor Dilation, Lorentz Force, Particle Mass and Energy as Invariants of Galilean Electrodynamics
* Adolphe Martin (Longueuil, Quebec) – Einstein to Galilean Relativity

Apeiron Number 19 (June 1994)
* S.H. Kim (University of Texas at Arlington) – A Non-Lorentzian Force Stronger than the Lorentz Force
* Constantin Antonopoulos (National Technological University of Athens) – The Semantics of Absolute Space * P. Graneau (Northeastern University, Arlington) and A.K.T. Assis (University of Campinas, Brazil) – Kirchhoff on the Motion of Electricity in Conductors
* Peter F. Browne (University of Manchester) – Newtonian Cosmology with Renormalized Zero-Point Radiation

Apeiron Number 20 (October 1994)
* V.A. Kuligin, G.A. Kuligina and M.V. Korneva (University of Voronezh, Russia) – Epistemology and Special Relativity * G. Galeczki (University of Kцln) – Physical Laws and the Theory of Special Relativity
* T. Chang (University of Alabama, Huntsville) – A Formulation of the Gravitational Equation of Motion

Aperion Volume 2, Number 1 (January 1995)
* Paul Marmet (University of Ottawa) – Origin

of the 3 K Radiation * Wen-Xiu Li (University of Science and Technology of China) – On the Relativity of Lengths and Times

Apeiron Volume 2, Number 2 (April 1995)
* Amitabha Ghosh (Indian Institute of Technology, Kanpur) – Dynamical Inertial Induction and the Potential Energy Problem * Halton C. Arp (Max-Planck-Institut fьr Astrophysik) – New Light on Redshift Periodicities

Apeiron Volume 2, Number 3 (July 1995)
* P.F. Browne (University of Manchester) – de Sitter Cosmology Reinterpreted
---------------------------- Articles and books by Robert L. Forward:

AUTHOR(s): Cramer, John G. Forward, Robert L. Landis, Geoffrey A.
Visser, M. Benford, G.
TITLE: Natural wormholes as gravitational lenses.
In: Physical Review-D: Particles, Fields, Gravitation Traversable wormholes, energy condition, time machines MAR 15 1995 v 51 n 6 Page 3117

AUTHOR(s): Forward, R.L.
TITLE: Statite: A Spacecraft That Does Not Orbit.
In: Journal of spacecraft and rockets.
SEP 01 1991 v 28 n 5 Page 606

AUTHOR(s): Forward, Robert
TITLE: Advanced Space Propulsion.
In: The Journal of social, political, and economic s Wint 1990 v 15 n 4 Page 387

AUTHOR(s): Forward, Robert L.
TITLE: Light-Levitated Geostationary Cylindrical Orbits:
Correction and Expansion.
In: The Journal of the astronautical sciences. JUL 01 1990 v 38 n 3 Page 335

AUTHOR(s): Forward, Robert L.
TITLE: Advanced space propulsion.
In: Aerospace america.
JUL 01 1990 v 28 n 7 Page 60

AUTHOR(s): Forward, Robert L.
TITLE: Grey Solar Sails.
In: The Journal of the astronautical sciences.
APR 01 1990 v 38 n 2 Page 161

AUTHOR(s): Forward, Robert
TITLE: The power of negative matter: Does matter with a negative
mass exist somewhere in the cosmos? If it does, it would make the perfect space-drive.
In: New scientist.
MAR 17 1990 v 125 n 1708 Page 54

AUTHOR(s): Forward, R.L.
TITLE: Solar Photon Thruster.
In: Journal of spacecraft and rockets.
JUL 01 1990 v 27 n 4 Page 411

AUTHOR(s): Forward, R.L.
TITLE: Negative matter Propulsion.
In: Journal of propulsion and power.
JAN 01 1990 v 6 n 1 Page 28

AUTHOR(s): Forward, R.L.
TITLE: Space Warps: A Review of One Form of Propulsionless
Transport.
In: JBIS; Journal of the British Interplanetary Society NOV 01 1989 v 42 n 11 Page 533

AUTHOR: Forward, Robert L.
TITLE: Negative Matter Propulsion
In: July 1988 AIAA Joint Propulsion Conference, Journal of Propulsion and Power Vol 6 no 1 pp 28-37

AUTHOR(S): Robert L. Forward and Joel Davis.
TITLE: Mirror Matter: Pioneering Antimatter Physics
Source: New York : Wiley, 1988.
Series: Wiley science editions

AUTHOR: Forward, Robert L.
TITLE: Spin Drive To The Stars
In: ANALOG, Apr 1981, pp. 64-7O

AUTHOR: Forward, R.L.
TITLE: Far Out Physics
In: Analog Science Fiction/Science Fact
Vol 95, August 1975 pages 147-166

TITLE: Bibliography of interstellar travel and communication: April 1977
AUTHOR: Mallove, Eugene F. and Forward, Robert L.

TITLE: Camelot 30K / 1993
AUTHOR: Forward, Robert L.

TITLE: Dragon's egg ; Starquake / 1994
AUTHOR: Forward, Robert L.

TITLE: The flight of the dragonfly / 1985
AUTHOR: Forward, Robert L.

TITLE: Indistinguishable from magic : speculations and visions of the future / 1995
AUTHOR: Forward, Robert L.

TITLE: Marooned on Eden / 1993
AUTHOR: Forward, Robert L.

TITLE: Martian rainbow / 1991
AUTHOR: Forward, Robert L.

TITLE: Mirror matter : pioneering antimatter physics / 1988 AUTHOR: Forward, Robert L.

TITLE: A national space program for interstellar exploration. 1975 AUTHOR: Forward, Robert L.

TITLE: Ocean under the ice / 1994
AUTHOR: Forward, Robert L.

TITLE: Rescued from paradise / 1995
AUTHOR: Forward, Robert L.

TITLE: Return to Rocheworld / 1993
AUTHOR: Forward, Robert L.

TITLE: Rocheworld / 1990
AUTHOR: Forward, Robert L.

TITLE: Starquake / 1986
AUTHOR: Forward, Robert L.

TITLE: Timemaster / 1992
AUTHOR: Forward, Robert L.

Dr. Harold Aspden recently retired after serving many years as IBM's patent agent in Europe. He is the discoverer of the "Aspden Effect" or rotational inertia in spinning magnets (NEN, Jan. & Feb. 1995). His Ph.D. thesis involved demonstrations of anomalies in magnetic fields

Books and articles by Harold Aspden:

AUTHOR: Aspden, Harold.
TITLE: Gravitation / by Harold Aspden.
PUBL.: Southampton, Eng. : Sabberton Publications,
FORMAT: 78 p. ; 22 cm.
DATE: 1975
SUBJECT Gravitation
ISBN: 0850560055. 0850560063

AUTHOR: Aspden, Harold.
TITLE: Modern aether science.
PUBL.: Southampton, Eng., Sabberton Publications
FORMAT: 165 p. illus. 22 cm.
DATE: 1972
SUBJECT Ether (Space)
ISBN: 0850560039 0850560047 (pbk)

AUTHOR: Aspden, Harold.
TITLE: The need for a new theory of gravitation, by H. Aspden.
PUBL.: Southampton (Hants.), Sabberton Publications,
FORMAT: (1), 4 p. 22 cm.
DATE: 1966
SERIES: His Aether science paper no. 1
SUBJECT: Gravitation
Relativity (Physics)

AUTHOR: Aspden, Harold.
TITLE: Physics unified / by Harold Aspden.
PUBL.: Southhampton : Sabberton Publications,
FORMAT: xi, 206 p. : ill. ; 22 cm.
DATE: 1980
SUBJECT Unified field theories
ISBN: 0850560101

AUTHOR: Aspden, Harold.
TITLE: Physics without Einstein.
PUBL.: Southampton, Sabberton Publications,

FORMAT: xiii, 224 p. illus. 23 cm.
DATE: 1969
SUBJECT Physics
ISBN: 850560012

AUTHOR(s): Aspden, H.
TITLE(s): Anti Gravity Electronics.
Summary: Reinterpretation of Newton's Third Law of Motion suggests
that it depends upon and electronic action. Electronic interaction therefore explains the paradoxical anti- gravity properties of the force processed gyroscope. In: Electronics & wireless world.
JAN 01 1989 v 95 n 1635 Page: 29

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TITLE(s): Conservative hadron interactions exemplified by the
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* Motion in a Schwarzschild Field I. Precession of a Moving Gyroscope, American Journal of Physics 37, 309 (1969). * Faster-Than-Light Inertl Review 188, 2287 (1969).
* Special Relativity and Diagonal Transformations (with G. Schmieg), American Journal of Physics 38, 218 (1970). * Quantized Matter Fields and the Avoidance of Singularities in General Relativity (with S. A. Fulling), Physical Review D7, 2357 (1973).
* Metric of Two Spinning Charged Sources in Equilibrium (with R. Ruffini and D. Wilkins), Physical Review D7, 2874 (1973). * Quantized Scalar Fields in a Closed Anisotropic Universe (with B. L. Hu and S. A. Fulling), Physical Review D8, 2377 (1973). * Adiabatic Regularization of the Energy-Momentum Tensor of a Quantized Field in Homogeneous Spaces (with S. A. Fulling), Physical Review D9, 341 (1974).
* Renormalization in the Theory of a Quantized Scalar Field Interacting With a Robertson-Walker Spacetime (with S. A. Fulling), Annals of Physics (N.Y.) 87, 176-203 (1974). * Adiabatic Analysis and Renormalization in Semiclassical Gravitation Theory (with S. A. Fulling), Bulletin American Physical Society 19 108 (1974).
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* The Production of Elementary Particles by Strong Gravitational Fields (120 pages), in Proceedings of the Symposium on Asymptotic Properties of Space-Time (Plenum Publishing Corp., New York, 1977), editors, P. Esposito and L. Witten. * Angular Momentum and Dirac Charge Quantization in Curved Spacetime, (with J. Friedman and S. Mayer), Physical Review D17, 1957 (1978).
* Applied Quantum Gravity: Applications of the Semiclassical Theory, in On the Path of Albert Einstein, edited by B. Kursunoglu, A. Perlmutter, and L. F. Scott (Plenum Press, New York, 1979), pp. 145-166.
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http://www.physics.wustl.edu/~visser/homepage.html

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Physics Letters B209 (1988) 209--213.

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Nuclear Physics B310 (1988) 163--180.

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(World Scientific, Singapore, 1990), volume 2, pp. 858--860.

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Remarks on Hawking's chronology protection conjecture. Physical Review D47 (1993) 554--565.

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Geodesic focussing and defocussing in Lorentzian spacetimes. Physical Review D47 (1993) 2395--2402.

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Dirty black holes: Entropy versus area.
Physical Review D48 (1993) 583--591.

Dirty black holes: Entropy as a surface term. Physical Review D48 (1993) 5697--5705.

Lateral wave contributions to the low--altitude radar propagation factor. With Gerald Gilbert and Eric Raiten
Radio Science 29 (1994) 483--494.

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Natural wormholes as gravitational lenses. With John Cramer, Robert Forward, Michael Morris, Gregory Benford, and Geoffrey Landis
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Scale anomalies imply violation of the averaged null energy condition. Physics Letters B349 (1995) 443--447.

Lorentzian Wormholes --- from Einstein to Hawking. Full length technical monograph.
American Institute of Physics Press, July 1995.

Acoustic propagation in fluids:
An unexpected example of Lorentzian geometry. gr-qc/9311028; gr-qc@xxx.lanl.gov.
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gr-qc/9506083; gr-qc@xxx.lanl.gov
Submitted for publication.

New book by Matt Visser. Published 1995
"Lorentzian Wormholes---from Einstein to Hawking", by Matt Visser (Washington University in St. Louis). American Institute of Physics Press (Woodbury, New York). ISBN 1-56396-394-9
412 pages (including index and 38 figures); hardback; US$59.00 (US$47.20 for APS/AIP members). To order---Voice: 1-800-809-2247; FAX: 1-802-864-7626. Table of contents:
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Chapter 3 Quantum field theory 31
Chapter 4 Units and natural scales 39
Part ii -- History 43
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Chapter 9 Wormhole taxonomy 89
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Part iii - Renaissance 97
Chapter 11 Traversable wormholes 99
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Chapter 25 Where we stand 369
-------------------------- Other articles about wormholes:

AUTHOR(s): Kar, Sayan Sahdev, Deshdeep
TITLE(s): Restricted class of traversable wormholes with traceless
matter.
In: Physical review d: particles, fields, gravitat
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AUTHOR(s): Wang, Anzhong Letelier, Patricio S.
TITLE(s): Dynamical Wormholes and energy Conditions.
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AUTHOR(s): Cramer, John G. Forward, Robert L. Landis, Geoffrey A.
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AUTHOR(s): Agnese, A.G. La Camera, M.
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AUTHOR(s): Cadoni, Mariano Cavaglia, Marco
TITLE(s): Cosmological and wormhole solutions in low-energy effective
string theory.
In: Physical review d: particles, fields, gravitat
NOV 15 1994 v 50 n 10 Page 6435

AUTHOR(s): Cavaglia, Marco
TITLE(s): Quantum electromagnetic wormholes and geometrical
description of the electric charge.
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AUTHOR(s): Singh, Harvendra
TITLE(s): Magnetic wormholes and vertex operators.
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AUTHOR(s): Ridgway, S. Alexander
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AUTHOR(s): Cotsakis, Spiros Leach, Peter Flessas, George
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AUTHOR(s): Visser, Matt
TITLE(s): van Vleck determinants: Traversable wormhole spacetimes.
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Electrogravitics Systems: *An examination of electrostatic motion, dynamic counterbary and barycentric control.* [1]

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Electrogravitics Systems

An examination of electrostatic motion, dynamic counterbary and barycentric control. It has been accepted as axiomatic that the way to offset the effects of gravity is to use a lifting surface and considerable molecular energy to produce a continuously applied force that, for a limited period of time, can remain greater than the effects of gravitational attraction. The original invention of the glider and evolution of the briefly self-sustaining glider, at the turn of the century led to progressive advances in power and knowledge. This has been directed to refining the classic Wright Brothers' approach. Aircraft design is still fundamentally as the Wrights adumbrated it, with wings, body, tails, moving or flapping controls, landing gear and so forth. The Wright biplane was a powered glider, and all subsequent aircraft, including the supersonic jets of the nineteen-fifties are also powered gliders. Only one fundamentally different flying principle has so far been adopted with varying degrees of success. It is the rotating wing aircraft that has led to the jet lifters and vertical pushers, coleopters, ducted fans and lift induction turbine propulsion systems. But during these decades there was always the possibility of making efforts to discover the nature of gravity from cosmic or quantum theory, investigation and observation, with a view to discerning the physical properties of aviation's enemy. It has seemed to Aviation Studies that for some time insufficient attention has been directed to this kind of research. If it were successful such developments would change the concept of sustentation, and confer upon a vehicle qualities that would now be regarded as the ultimate in aviation. This report summarizes in simple form the work that has been done and is being done in the new field of electrogravitics. It also outlines the various possible lines of research into the nature and constituent matter of gravity, and how it has changed from Newton to Einstein to the modern Hlavaty concept of gravity as an electromagnetic force that may be controlled like a light wave. The report also contains an outline of opinions on the feasibility of different electrogravitics systems and there is reference to some of the barycentric control and electrostatic rigs in operation. Also included is a list of references to electrogravitics in successive Aviation Reports since a drive was started

[1] The current article was not prepared by the Air Force but by an organization called Gravity Research Group, Special Weapons Study Unit, a subdivision of Aviation Studies (International) Ltd. from the UK Aviation Studies was a research group ran by two young aerospace analysts Richard Worcester and John Longhurst, who in mid-1950 also published an aerospace and defense industry newsletter. [Venik]

by Aviation Studies (International) Limited to suggest to aviation business eighteen months ago that the rewards of success are too far- reaching to be overlooked, especially in view of the hopeful judgement of the most authoritative voices in microphysics. Also listed are some relevant patents on electrostatics and electrostatic generators in the United States, United Kingdom and France. [Signed] Gravity Research Group 25 February 1956

Discussion

Electrogravitics might be described as a synthesis of electrostatic energy used for propulsion - either vertical propulsion or horizontal or both - and gravitics, or dynamic counterbary, in which energy is also used to set up a local gravitational force independent of the earth's. Electrostatic energy for propulsion has been predicted as a possible means of propulsion in space when the thrust from a neutron motor or ion motor would be sufficient in a dragless environment to produce astronomical velocities. But the ion motor is not strictly a part of the science of electrogravitics, since barycentric control in an electrogravitics system is envisaged for a vehicle operating within the earth's environment and it is not seen initially for space application. Probably large scale space operations would have to await the full development of electrogravitics to enable large pieces of equipment to be moved out of the region of the earth's strongest gravity effects. So, though electrostatic motors were thought of in 1925, electrogravitics had its birth after the War, when Townsend Brown sought to improve on the various proposals that then existed for electrostatic motors sufficiently to produce some visible manifestation of sustained motion. Whereas earlier electrostatic tests were essentially pure research, Brown's rigs were aimed from the outset at producing a flying article. As a private venture he produced evidence of motion using condensers in a couple of saucers suspended by arms rotating round a central tower with input running down the arms. The massive-k situation was summarized subsequently in a report, Project Winterhaven, in 1952. Using the data some conclusions were arrived at that might be expected from ten or more years of intensive development - similar to that, for instance, applied to the turbine engine. Using a number of assumptions as to the nature of gravity, the report postulated a saucer as the basis of a possible interceptor with Mach 3 capability. Creation of a local gravitational system would confer upon the fighter the sharp-edged changes of direction typical of motion in space. The essence of electrogravitics thrust is the use of a very strong positive charge on one side of the vehicle and a negative on the other. The core of the motor is a condenser and the ability of the condenser to hold its charge (the k-number) is the yardstick of performance. With air as 1, current dielectrical materials can yield 6 and use of barium aluminate can raise this considerably, barium titanium oxide (a baked ceramic) can offer 6,000 and there is promise of 30,000, which would be sufficient for supersonic speed. The original Brown rig produced 30 fps on a voltage of around 50,000 and a small amount of current in the milliamp range. There was no detailed explanation of gravity in Project Winterhaven, but it was assumed that particle dualism in the subatomic structure of gravity would coincide in its effect with the issuing stream of electrons from the electrostatic energy source to produce counterbary. The Brown work probably remains a realistic approach to the practical realization of electrostatic propulsion and sustentation. Whatever may be discovered by the Gravity Research Foundation of New Boston a complete understanding and synthetic reproduction of gravity is not essential for limited success. The electrogravitics saucer can perform the function of a classic lifting surface - it produces a pushing effect on the under surface and a suction effect on the upper, but, unlike the airfoil, it does not require a flow of air to produce the effect. First attempts at electrogravitics are unlikely to produce counterbary, but may lead to development of an electrostatic VTOL vehicle. Even in its developed form this might be an advance on the molecular heat engine in its capabilities. But hopes in the new science depend on an understanding of the close identity of electrostatic motivating forces with the source and matter of gravity. It is fortuitous that lift can be produced in the traditional fashion and if an understanding of gravity remains beyond full practical control, electrostatic lift might be an adjunct of some significance to modern thrust producers. Research into electrostatics could prove beneficial to turbine development, and heat engines in general, in view of the usable electron potential round the periphery of any flame. Materials for electrogravitics and especially the development of commercial quantities of high-k material is another dividend to be obtained from electrostatic research even if it produces no counterbary. This is a line of development that Aviation Studies, Gravity Research Group is following. One of the interesting aspects of electrogravitics is that a breakthrough in almost any part of the broad front of general research on the intranuclear processes may be translated into a meaningful advance towards the feasibility of electrogravitics systems. This demands constant monitoring in the most likely areas of the physics of high energy sub-nuclear particles. It is difficult to be overoptimistic about the prospects of gaining so complete a grasp of gravity while the world's physicists are still engaged in a study of fundamental particles - that is to say those that cannot be broken down any more. Fundamental particles are still being discovered - the most recent was the Segre-Chamberlain-Wiegand attachment to the bevatron, which was used to isolate the missing anti-proton, which must - or should be presumed to - exist according to Dirac's theory of the electron. Much of the accepted mathematics of particles would be wrong if the anti-proton was proved to be non-existent. Earlier Eddington has listed the fundamental particles as:- e. The charge of an electron m. The mass of an electron. M. The mass of a proton. h. Planck's constant c. The velocity of light. G. The constant of gravitation, and [Greek letter, small lambda]. The cosmical constant. It is generally held that no one of these can be inferred from the others. But electrons may well disappear from among the fundamental particles, though, as Russell says, it is likely that e and m will survive. The constants are much more established than the interpretation of them and are among the most solid of achievements in modern physics.

Gravity may be defined as a small scale departure from Euclidean space in the general theory of relativity. The gravitational constant is one of four dimensionless constants: first, the mass relation of the nucleon and electron. Second is (e*e)/(h*c) [equation form], third, the Compton wavelength of the proton, and fourth is the gravitational constant, which is the ratio of the electrostatic to the gravitational attraction between the electron and the proton. One of the stumbling blocks in electrogravitics is the absence of any satisfactory theory linking these four dimensionless quantities. Of the four, moreover, gravity is decidedly the most complex, since any explanation would have to satisfy both cosmic and quantum relations more acceptably and intelligibly even than in the unified field theory. A gravitational constant of around 10.E-39 [equation form] has emerged from quantum research and this has been used as a tool for finding theories that could link the two relations. This work is now in full progress, and developments have to be watched for the aviation angle. Hitherto Dirac, Eddington, Jordan and others have produced differences in theory that are too wide to be accepted as consistent. It means therefore that (i) without a cosmical basis, and (ii) with an imprecise quantum basis and (iii) a vague hypothesis on the interaction, much remains still to be discovered. Indeed some say that a single interacting theory to link up the dimensionless constants is one of three major unresolved basic problems of physics. The other two main problems are the extension of quantum theory and a more detailed knowledge of the fundamental particles. All this is some distance from Newton, who saw gravity as a force acting on a body from a distance, leading to the tendency of bodies to accelerate towards each other. He allied this assumption with Euclidean geometry, and time was assumed as uniform and acted independently of space. Bodies and particles in space normally moved uniformly in straight lines according to Newton, and to account for the way they sometimes do not do so, he used the idea of a force of gravity acting at a distance, in which particles of matter cause in others an acceleration proportional to their mass, and inversely proportional to the square of the distance between them. But Einstein showed how the principle of least action, or the so-called cosmic laziness means that particles, on the contrary, follow the easiest path along geodesic lines and as a result they get readily absorbed into space-time. So was born non-linear physics. The classic example of non- linear physics is the experiment in bombarding a screen with two slits. When both slits are open particles going through are not the sum of the two individually but follows a non-linear equation. This leads on to wave-particle dualism and that in turn to the Heisenberg uncertainty principle in which an increase in accuracy in measurement of one physical quantity means decreasing accuracy in measuring the other. If time is measured accurately energy calculations will be in error; the more accurate the position of a particle is established the less certain the velocity will be; and so on. This basic principle of the acausality of microphysics affects the study of gravity in the special and general theories of relativity. Lack of pictorial image in the quantum physics of this interrelationship is a difficulty at the outset for those whose minds remain obstinately Euclidean. In the special theory of relativity, space-time is seen only as an undefined interval which can be defined in any way that is convenient and the Newtonian idea of persistent particles in motion to explain gravity cannot be accepted. It must be seen rather as a synthesis of forces in a four dimensional continuum, three to establish the position and one the time. The general theory of relativity that followed a decade later was a geometrical explanation of gravitation in which bodies take the geodesic path through space-time. In turn this means that instead of the idea of force acting at a distance it is assumed that space, time, radiation and particles are linked and variations in them from gravity are due rather to the nature of space. Thus gravity of a body such as the earth instead of pulling objects towards it as Newton postulated, is adjusting the characteristics of space and, it may be inferred, the quantum mechanics of space in the vicinity of the gravitational force. Electrogravitics aims at correcting this adjustment to put matter, so to speak, 'at rest'.

One of the difficulties in 1954 and 1955 was to get aviation to take electrogravitics seriously. The name alone was enough to put people off. However, in the trade much progress has been made and now most major companies in the United States are interested in counterbary. Groups are being organised to study electrostatic and electromagnetic phenomena. Most of industry's leaders have made some reference to it. Douglas has now stated that it has counterbary on its work agenda but does not expect results yet awhile. Hiller has referred to new forms of flying platform, Glenn Martin say gravity control could be achieved in six years, but they add that it would entail a Manhattan District type of effort to bring it about. Sikorsky, one of the pioneers, more or less agrees with the Douglas verdict and says that gravity is tangible and formidable, but there must be a physical carrier for this immense trans-spatial force. This implies that where a physical manifestation exists, a physical device can be developed for creating a similar force moving in the opposite direction to cancel it. Clarke Electronics state they have a rig, and add that in their view the source of gravity's force will be understood sooner than some people think. General Electric is working on the use of electronic rigs designed to make adjustments to gravity - this line of attack has the advantage of using rigs already in existence for other defence work. Bell also has an experimental rig intended, as the company puts it, to cancel out gravity, and Lawrence Bell has said he is convinced that practical hardware will emerge from current programs. Grover Leoning is certain that what he referred to as an electro-magnetic contra-gravity mechanism will be developed for practical use. Convair is extensively committed to the work with several rigs. Lear Inc., autopilot and electronic engineers have a division of the company working on gravity research and so also has the Sperry division of Sperry-Rand. This list embraces most of the U.S. aircraft industry. The remainder, Curtiss-Wright, Lockheed, Boeing and North American have not yet declared themselves, but all these four are known to be in various stages of study with and without rigs. In addition, the Massachusetts Institute of Technology is working on gravity, the Gravity Research Foundation of New Boston, the Institute for Advanced Study at Princeton, the CalTech Radiation Laboratory, Princeton University and the University of North Carolina are all active in gravity. Glenn L. Martin is setting up a Research Institute for Advanced Study which has a small staff working on gravity research with the unified field theory and this group is committed to extensive programs of applied research. Many others are also known to be studying gravity, some are known also to be planning a general expansion in this field, such as in the proposed Institute for Pure Physics at the University of North Carolina. A certain amount of work is also going on in Europe. One of the French nationalized constructors and one company outside the nationalized elements have been making preliminary studies, and a little company money has in one case actually been committed. Some work is also going on in Britain where rigs are now in existence. Most of it is private venture work, such as that being done by Ed Hull a colleague of Townsend Brown who, as much as anybody, introduced Europe to electrogravitics. Aviation Studies' Gravity Research Group is doing some work, mainly on k studies, and is sponsoring dielectric investigations. One Swedish company and two Canadian companies have been making studies, and quite recently the Germans have woken up to the possibilities. Several of the companies have started digging out some of the early German papers on wave physics. They are almost certain to plan a gravitics program. Curiously enough the Germans during the war paid no attention to electrogravitics. This is one line of advance that they did not pioneer in any way and it was basically a U.S. creation. Townsend Brown in electrogravitics is the equivalent of Frank Whittle in gas turbines. This German overlooking of electrostatics is even more surprising when it is remembered how astonishingly advanced and prescient the Germans were in nuclear research. (The modern theory of making thermonuclear weapons without plutonium fission initiators returns to the original German idea that was dismissed, even ridiculed. The Germans never went very far with fission, indeed they doubted that this chain would ever be made to work. The German air industry, still in the embryo stage, has included electrogravitics among the subjects it intends to examine when establishing the policy that the individual companies will adopt after the present early stage of foreign licence has enabled industry to get abreast of the other countries in aircraft development.

It is impossible to read through this summary of the widening efforts being made to understand the nature of matter of gravity without sharing the hope that many groups now have, of major theoretical breakthroughs occurring before very long. Experience in nucleonics has shown that when attempts to win knowledge on this scale are made, advances are soon seen. There are a number of elements in industry, and some managements, who see gravity as a problem for later generations. Many see nothing in it all and they may be right. But as said earlier, if Dr. Vaclav Hlavaty thinks gravity is potentially controllable that surely should be justification enough, and indeed inspiration, for physicists to apply their minds and for management to take a risk. Hlavaty is the only man who thinks he can see a way of doing the mathematics to demonstrate Einstein's unified field theory - something that Einstein himself said was beyond him. Relativity and the unified field theory go to the root of electrogravitics and the shifts in thinking, the hopes and fears, and a measure of progress is to be obtained only in the last resort from men of this stature. Major theoretical breakthroughs to discover the sources of gravity will be made by the most advanced intellects using the most advanced research tools. Aviation's role is therefore to impress upon physicists of this calibre with the urgency of the matter and to aid them with statistical and peripheral investigations that will help to clarify the background to the central mathematical and physical puzzles. Aviation could also assist by recruiting some of these men as advisers. Convair has taken the initiative with its recently established panel of advisers on nuclear projects, which include Dr. Edward Teller of the University of California. At the same time much can be done in development of laboratory rigs, condenser research and dielectric development, which do not require anything like the same cerebral capacity to get results and make a practical contribution As gravity is likely to be linked with the new particles, only the highest powered particle accelerators are likely to be of use in further fundamental knowledge. The country with the biggest tools of this kind is in the best position to examine the characteristics of the particles and from those countries the greatest advances seem most likely. Though the United States has the biggest of the bevatron - the Berkeley bevatron is 6.2 bev - the Russians have a 10 bev accelerator in construction which, when it is completed, will be the world's largest. At Brookhaven a 25 bev instrument is in development which, in turn, will be the biggest. Other countries without comparable facilities are of course at a great disadvantage from the outset in the contest to discover the explanation of gravity. Electrogravitics, moreover, unfortunately competes with nuclear studies for its facilities. The clearest thinking brains are bound to be attracted to localities where the most extensive laboratory equipment exists. So, one way and another, results are most likely to come from the major countries with the biggest undertakings. Thus the nuclear facilities have a direct bearing on the scope for electrogravitics work. The OEEC report in January made the following points:- The U.S. has six to eight entirely different types of reactor in operation and many more under construction. Europe has now two different types in service. The U.S. has about 30 research reactors plus four in Britain,, two in France. The U.S. has two nuclear-powered marine engines. Europe has none, but the U.K. is building one. Isotope separation plants for the enrichment of uranium in the U.S. are roughly 11 times larger than the European plant in Britain. Europe's only heavy water plant (in Norway) produces somewhat less than one-twentieth of American output. In 1955 the number of technicians employed in nuclear energy work in the U.S. was about 15,000; there are about 5,000 in Britain, 1,800 in France, and about 19,000 in the rest of Europe. But the working party says that pessimistic conclusions should not be drawn from these comparisons. European nuclear energy effort is unevenly divided at the moment, but some countries have notable achievements to their credit and important developments in prospect. The main reason for optimism is that, taken as a whole, "Europe's present nuclear effort falls very far short of its industrial potential". Though gravity research, such as there has been of it, has been unclassified, new principles and information gained from the nuclear research facilities that have a vehicle application is expected to be withheld. The heart of the problem to understanding gravity is likely to prove to be the way in which the very high energy sub-nuclear particles convert something, whatever it is, continuously and automatically into the tremendous nuclear and electromagnetic forces. Once this key is understood, attention can later be directed to finding laboratory means of duplicating the process and reversing its force lines in some local environment and returning the energy to itself to produce counterbary. Looking beyond it seems possible that gravitation will be shown to be a part of the universal electro-magnetic processes and controlled in the same way as a light wave or radio wave. This is a synthesis of the Einstein and Hlavaty concepts. Hence it follows that though in its initial form the mechanical processes for countering gravity may initially be massive to deal with the massive forces involved, eventually this could be expected to form some central power generation unit. Barycentric control in some required quantity could be passed over a distance by a form of radio wave. The prime energy source to energise the waves would of course be nuclear in its origins. It is difficult to say which lines of detailed development being processed in the immediate future is more likely to yield significant results. Perhaps the three most promising are: first, the new attempt by the team of men led by Chamberlain working with the Berkeley bevatron to find the anti-neutron, and to identify more of the characteristics of the anti-proton[2] and each of the string of high energy particles that have been discovered during recent operation at 6. 2 bev. A second line of approach is the United States National Bureau of Standards program to pin down with greater accuracy the acceleration values of gravity. The presently accepted figure of 32.174 feet per second per second is known to be not comprehensive, though it has been sufficiently accurate for the limited needs of industry hitherto. The NBS program aims at re-determining the strength of gravity to within one part of a million. The present method has been to hold a ball 16 feet up and chart the elapsed time of descent with electronic measuring equipment. The new program is based on the old, but with this exceptional degree of accuracy it is naturally immensely more difficult and is expected to take 3 years. A third promising line is the new technique of measuring high energy particles in motion that was started by the University of California last year. This involves passing cosmic rays through a chamber containing a mixture of gas, alcohol and water vapour. This creates charged atoms, or positive ions, by knocking electrons off the gas molecules. A sudden expansion of the chamber results in a condensation of water droplets along the track which can be plotted on a photographic plate. This method makes it easier to assess the energy of particles and to distinguish one from the other. It also helps to establish the characteristics of the different types of particle. The relationship between these high energy particles and their origin, and characteristics have a bearing on electrogravitics in general. So much of what has to be discovered as a necessary preliminary to gravity is of no practical use by itself. There is no conceivable use, for instance, for the anti-proton, yet its discovery even at a cost of $9-million is essential to check the mathematics of the fundamental components of matter. Similarly it is necessary to check that all the nuclear ghosts that have been postulated theoretically do in fact exist. It is not, moreover, sufficient, as in the past, only to observe the particles by radiation counters. In each instance a mechanical maze has to be devised and attached to a particle accelerator to trap only the particle concerned. Each discovery becomes a wedge for a deeper probe of the nucleus. Many of the particles of very high energy have only a fleeting existence and collisions that give rise to them from bevatron bombardment is a necessary prerequisite to an understanding of gravity. There are no shortcuts to this process. Most of the major programs for extending human knowledge on gravity are being conducted with instruments already in use for nuclear research and to this extent the cost of work exclusively on gravitational examinations is still not of major proportions. This has made it difficult for aviation to gauge the extent of the work in progress on gravity research.

[2] The reaction is as follows: protons are accelerated to 6.2 bev, and directed at a target of copper. When the proton projectile hits a neutron in one of the copper atoms the following emerge: the two original particles (the projectile and the struck neutron) and a new pair of particles, a proton and anti-proton. The anti-proton continues briefly until it hits another proton, then both disappear and decay into mesons

Conclusions

1. No attempts to control the magnitude or direction of the earth's gravitational force have yet been successful. But if the explanation of gravity is to be found in the as yet undetermined characteristics of the very high energy particles it is becoming increasingly possible with the bevatron to work with the constituent matter of gravity. It is therefore reasonable to expect that the new bevatron may, before long, be used to demonstrate limited gravitational control.
2. An understanding and identification of these particles is on the frontiers of human knowledge, and a full assessment of them is one of the major unresolved puzzles of the nucleus. An associated problem is to discover a theory to account for the cosmic and quantum relations of gravity, and a theory to link the gravitational constant with the other three dimensionless constants.
3. Though the obstacles to an adequate grasp of microphysics still seem formidable, the transportation rewards that could follow from electrogravitics are as high as can be envisaged. In a weightless environment, movement with sharp-edged changes of direction could offer unique manoeuvrability.
4. Determination of the environment of the anti-proton, discovery of the anti-neutron and closer examination of the other high energy particles are preliminaries to the hypothesis that gravity is one aspect of electromagnetism that may eventually be controlled like a wave. When the structure of the nucleus becomes clearer, the influence of the gravitational force upon the nucleus and the nature of its behaviour in space will be more readily understood. This is a great advance on the Newtonian concept of gravity acting at a distance.
5. Aviation's role appears to be to establish facilities to handle many of the peripheral and statistical investigations to help fill in the background on electrostatics.
6. A distinction has to be made between electrostatic energy for propulsion and counterbary. Counterbary is the manipulation of gravitational force lines; barycentric control is the adjustment to such manipulative capability to produce a stable type of motion suitable for transportation.
7. Electrostatic energy sufficient to produce low speeds (a few thousand dynes, has already been demonstrated. Generation of a region of positive electrostatic energy on one side of a plate and negative on the other sets up the same lift or propulsion effect as the pressure and suction below and above a wing, except that in the case of electrostatic application no airflow is necessary.
8. Electrostatic energy sufficient to produce a Mach 3 fighter is possible with megavolt energies and a k of over 10,000.
9. k figures of 6,000 have been obtained from some ceramic materials and there are prospects of 30,000.

10. Apart from electrogravitics there are other rewards from investment in electrostatic equipment. Automation, autonetics and even turbine development use similar laboratory facilities.
11. Progress in electrogravitics probably awaits a new genius in physics who can find a single equation to tie up all the conflicting observations and theory on the structure and arrangement of forces and the part the high energy particles play in the nucleus. This can occur any time, and the chances are improved now that bev. energies are being obtained in controlled laboratory conditions.

Appendix I

Extracts From Aviation Report Anti-Gravitation Research

The basic research and technology behind electro-anti-gravitation is so much in its infancy that this is perhaps one field of development where not only the methods but the ideas are secret. Nothing therefore can be discussed freely at the moment. Very few papers on the subject have been prepared so far, and the only schemes that have seen the light of day are for pure research into rigs designed to make objects float around freely in a box. There are various radio applications, and aviation medicine departments have been looking for something that will enable them to study the physiological effects on the digestion and organs of an environment without gravity. There are however long term aims of a more revolutionary nature that envisage equipment that can defeat gravity. Aviation Report 20 August 1954 MANAGERIAL POLICY FOR ANTI-GRAVITICS The prospect of engineers devising gravity-defeating equipment - or perhaps it should be described as the creation of pockets of weightless environments - does suggest that as a long term policy aircraft constructors will be required to place even more emphasis on electro-mechanical industrial plant, than is now required for the transition from manned to unmanned weapons. Anti-gravitics work is therefore likely to go to companies with the biggest electrical laboratories and facilities. It is also apparent that anti-gravitics, like other advanced sciences, will be initially sponsored for its weapon capabilities. There are perhaps two broad ways of using the science - one is to postulate the design of advanced type projectiles on their best inherent capabilities, and the more critical parameters (that now constitutes the design limitation) can be eliminated by anti-gravitics. The other, which is a longer term plan, is to create an entirely new environment with devices operating entirely under an anti-gravity envelope. Aviation Report 24 August 1954 THE GREATER THE EASIER Propulsion and atomic energy Trends are similar in one respect: the more incredible the long term capabilities are, the easier it is to attain them. It is strange that the greatest of nature's secrets can be harnessed with decreasing industrial effort, but greatly increasing mental effort. The Americans went through the industrial torture to produce tritium for the first thermonuclear experiment, but later both they and the Russians were able to achieve much greater results with the help of lithium 6 hydride. The same thing is happening in aviation propulsion: the nuclear fuels are promising to be tremendously powerful in their effect, but excessively complicated in their application, unless there can be some means of direct conversion as in the strontium 90 cell. But lying behind and beyond the nuclear fuels is the linking of electricity to gravity, which is an incomparably more powerful way of harnessing energy than the only method known to human intellect at present - electricity and magnetism. Perhaps the magic of barium aluminium oxide will perform the miracle in propulsion that lithium 6 hydride has done in the fusion weapon. Certainly it is a well-known material in dielectrics, but when one talks of massive-k, one means of course five figures. At this early stage it is difficult to relate k to Mach numbers with any certainty, but realizable k can, with some kinds of arithmetic, produce astounding velocities. They are achievable, moreover, with decreasing complexity, indeed the ultimate becomes the easiest in terms of engineering, but the most hideous in terms of theory. Einstein's general theory of relativity is, naturally, and important factor, but some of the postulates appear to depend on the unified field theory, which cannot yet be physically checked because nobody knows how to do it. Einstein hopes to find a way of doing so before he dies. Aviation Report 31 August 1954 GRAVITICS FORMULATIONS All indications are that there has still been little cognizance of the potentialities of electrostatic propulsion and it will be a major undertaking to re-arrange aircraft plants to conduct large-scale research and development into novel forms of dielectric and to improve condenser efficiencies and to develop the novel type of materials used for fabrication of the primary structure. Some extremely ambitious theoretical programs have been submitted and work towards realization of a manned vehicle has begun. On the evidence, there are far more definite indications that the incredible claims are realizable than there was, for instance, in supposing that uranium fission would result in a bomb. At least it is known, proof positive, that motion, using surprisingly low k, is possible. The fantastic control that again is feasible, has not yet been demonstrated, but there is no reason to suppose the arithmetic is faulty, especially as it has already led to a quite brisk example of actual propulsion. That first movement was indeed an historic occasion, reminiscent of the momentous day at Chicago when the first pile went critical, and the phenomenon was scarcely less weird. It is difficult to imagine just where a well-organised examination into long term gravitics prospects would end. Though a circular platform is electrostatically convenient, it does not necessarily follow that the requirements of control by differential changes would be the same. Perhaps the strangest part of this whole chapter is how the public managed to foresee the concept though not of course the theoretical principles that gave rise to it, before physical tests confirmed that the mathematics was right. It is interesting also that there is no point of contact between the conventional science of aviation and the New: it is a radical offshoot with no common principles. Aerodynamics, structures, heat engines, flapping controls, and all the rest of aviation is part of what might be called the Wright Brothers era - even the Mach 2.5 thermal barrier piercers are still Wright Brothers concepts, in the sense that they fly and they stall, and they run out of fuel after a short while, and they defy the earth's pull for a short while. Thus this century will be divided into two parts - almost to the day. The first half belonged to the Wright Brothers who foresaw nearly all the basic issues in which gravity was the bitter foe. In part of the second half gravity will be the great provider. Electrical energy, rather irrelevant for propulsion in the first half becomes a kind of catalyst to motion, in the second half of the century. Aviation Report 7 September 1954 ELECTRO-GRAVITICS PARADOX Realization of electro-static propulsion seems to depend on two theoretical twists and two practical ones. The two theoretical puzzles are: first, how to make a condenser the centre of a propulsion system, and second is how to link the condenser system with the gravitational field. There is a third problem, but it is some way off yet, which is how to manipulate kva for control in all three axes as well as for propulsion and lift. The two practical tricks are first how, with say a Mach 3 weapon in mind, to handle 50,000 kva within the envelope of a thin pancake of 35 feet in diameter and second how to generate such power from within so small a space. The electrical power in a small aircraft is more than is a fair sized community the analogy being that a single rocketjet can provide as much power as can be obtained from the Hoover Dam. It will naturally take as long to develop electro-static propulsion as it has taken to coax the enormous power outputs from heat engines. True there might be a flame in the electro-gravitic propulsion system, but it would not be a heat engine - the temperature of the flame would be incidental to the function of the chemical burning process. The curious thing is that though electro-static propulsion is the antithesis of magnetism,[3] Einstein's unified field theory is an attempt to link gravitation with electro-magnetism. This all-embracing theory goes on logically from the general theory of relativity, that gives an ingenious geometrical interpretation of the concept of force which is mathematically consistent with gravitation but fails in the case of electro-magnetism, while the special theory of relativity is concerned with the relationship between mass and energy. The general theory of relativity fails to account for electro-magnetism because the forces are proportional to the charge and not to the mass. The unified field theory is one of a number of attempts that have been made to bridge this gap, but it is baffling to imagine how it could ever be observed. Einstein himself thinks it is virtually impossible. However Hlavaty claims now to have solved the equations by assuming that gravitation is a manifestation of electro-magnetism. This being so it is all the more incredible that electro-static propulsion (with kva for convenience fed into the system and not self- generated) has actually been demonstrated. It may be that to apply all this very abstruse physics to aviation it will be necessary to accept that the theory is more important than this or that interpretation of it. This is how the physical constants, which are now regarded as among the most solid of achievements in modern physics, have become workable, and accepted. Certainly all normal instincts would support the Einstein series of postulations, and if this is so it is a matter of conjecture where it will lead in the long term future of the electro-gravitic science.

Aviation Report, 10 September 1954

Electro-Gravitic Propulsion Situation

Under the terms of Project Winterhaven the proposals to develop electro-gravitics to the point of realizing a Mach 3 combat type disc were not far short of the extensive effort that was planned for the Manhattan District.[4] Indeed the drive to develop the new prime mover is in some respects rather similar to the experiments

[3] Though in a sense this is true, it is better expressed in the body of this report than it was here in 1954.

[4] The proposals, it should be added, were not accepted.

that led to the release of nuclear energy in the sense that both involve fantastic mathematical capacity and both are sciences so new that other allied sciences cannot be of very much guide. In the past two years since the principle of motion by means of massive-k was first demonstrated on a test rig, progress has been slow. But the indications are now that the Pentagon is ready to sponsor a range of devices help further knowledge. In effect the new family of TVs would be on the same tremendous scope that was envisaged by the X-1, 2, 3, 4 and 5 and D.558s that were all created for the purpose of destroying the sound barrier - which they effectively did, but it is a process that is taking ten solid years of hard work to complete. (Now after 7 years the X-2 has yet to start its tests and the X-3 is still in performance testing stage). Tentative targets now being set anticipate that the first disc should be complete before 1960 and it would take the whole of the 'sixties to develop it properly, even though some combat things might be available ten years from now. One thing seems certain at this stage, that the companies likely to dominate the science will be those with the biggest computors to work out the ramifications of the basic theory. Douglas is easily the world's leader in computor capacity, followed by Lockheed and Convair. The frame incidentally is indivisible from the engine". If there is to be any division of responsibility it would be that the engine industry might become responsible for providing the electrostatic energy (by, it is thought, a kind of flame) and the frame maker for the condenser assembly which is the core of the main structure.

Aviation Report 12 October 1954

Gravitics Study Widening

The French are now understood to be pondering the most effective way of entering the field of electro-gravitic propulsion systems. But not least of the difficulties is to know just where to begin. There are practically no patents so far that throw very much light on the mathematics of the relation between electricity and gravity. There is, of course, a large number of patents on the general subject of motion and force, and some of these may prove to have some application. There is, however, a series of working postulations embodied in the original Project Winterhaven, but no real attempt has been made in the working papers to go into the detailed engineering. All that had actually been achieved up to just under a year ago was a series of fairly accurate extrapolations from the sketchy data that has so far been actually observed. The extrapolation of 50 mph to 1,800 mph, however, (which is what the present hopes and aspirations amount to) is bound to be a rather vague exercise. This explains American private views that nothing can be reasonably expected from the science yet awhile. Meanwhile, the NACA is active, and nearly all the Universities are doing work that borders close to what is involved here, and something fruitful is likely to turn up before very long. Aviation Report 19 October 1954 GRAVITICS STEPS Specification writers seem to be still rather stumped to know what to ask for in the very hazy science of electro-gravitic propelled vehicles. They are at present faced with having to plan the first family of things - first of these is the most realistic type of operational test rig, and second the first type of test vehicle. In turn this would lead to sponsoring of a combat disc. The preliminary test rigs which gave only feeble propulsion have been somewhat improved, but of course the speeds reached so far are only those more associated with what is attained on the roads rather than in the air. But propulsion is now known to be possible, so it is a matter of feeding enough KVA into condensers with better k figures. 50,000 is a magic figure for the combat saucer - it is this amount of KVA and this amount of k that can be translated into Mach 3 speeds. Meanwhile Glenn Martin now feels ready to say in public that they are examining the unified field theory to see what can be done. It would probably be truer to say that Martin and other companies are now looking for men who can make some kind of sense out of Einstein's equations. There's nobody in the air industry at present with the faintest idea of what it is all about. Also, just as necessary, companies have somehow to find administrators who know enough of the mathematics to be able to guess what kind of industrial investment is likely to be necessary for the company to secure the most rewarding prime contracts in the new science. This again is not so easy since much of the mathematics just cannot be translated into words. You either understand the figures, or you cannot ever have it explained to you. This is rather new because even things like indeterminacy in quantum mechanics can be more or less put into words. Perhaps the main thing for management to bear in mind in recruiting men is that essentially electro-gravitics is a branch of wave technology and much of it starts with Planck's dimensions of action, energy and time, and some of this is among the most firm and least controversial sections of modern atomic physics. Aviation Report 19 November 1954. ELECTROGRAVITICS PUZZLE Back in 1948 and 49, the public in the U.S. had a surprisingly clear idea of what a flying saucer should, or could, do. There has never at any time been any realistic explanation of what propulsion agency could make it do those things, but its ability to move within its own gravitation field was presupposed from its manoeuvrability. Yet all this was at least two years before electro-static energy was shown to produce propulsion. It is curious that the public were so ahead of the empiricists on this occasion, and there are two possible explanations. One is that optical illusions or atmospheric phenomena offered a preconceived idea of how the ultimate aviation device ought to work. The other explanation might be that this was a recrudescence of Jung's theory of the Universal Mind which moves up and down in relation to the capabilities of the highest intellects and this may be a case of it reaching a very high peak of perception. But for the air industries to realize an electro-gravitic aircraft means a return to basic principles in nuclear physics, and a re-examination of much in wave technology that has hitherto been taken for granted. Anything that goes any way towards proving the unified field theory will have as great a bearing on electro-gravitics efforts as on the furtherance of nuclear power generally. But the aircraft industry might as well face up to the fact that priorities will in the end be competing with the existing nuclear science commitments. The fact that electro-gravitics has important applications other than for a weapon will however strengthen the case for governments to get in on the work going on. Aviation Report 28 January 1955 MANAGEMENT NOTE FOR ELECTRO-GRAVITICS The gas turbine engine produced two new companies in the U.S. engine field and they have, between them, at various times offered the traditional primes rather formidable competition. Indeed GE at this moment has, in the view of some, taken the Number Two position. In Britain no new firms managed to get a footing but one, Metro-Vick, might have done if it had put its whole energies into the business. It is on the whole unfortunate for Britain that no bright newcomer has been able to screw up competition in the engine field as English Electric have done in the airframe business. Unlike the turbine engine, electro-gravitics is not just a new propulsion system, it is a new mode of thought in aviation and communications, and it is something that may become all-embracing. Theoretical studies of the science unfortunately have to extend right down to the mathematics of the meson and there is no escape from that. But the relevant facts wrung from the nature of the nuclear structure will have their impact on the propulsion system, the airframe and also its guidance. The airframe, as such, would not exist, and what is now a complicated stressed structure becomes some convenient form of hard envelope. New companies therefore who would like to see themselves as major defence prime contractors in ten or fifteen years time are the ones most likely to stimulate development. Several typical companies in Britain and the U.S. come to mind - outfits like AiResearch, Raytheon, Plessey in England, Rotax and others. But the companies have to face a decade of costly research into theoretical physics and it means a great deal of trust. Companies are mostly overloaded already and they cannot afford it, but when they sit down and think about the matter they can scarcely avoid the conclusion that they cannot afford not to be in at the beginning. Aviation Report 8 February 1955 ELECTRO-GRAVITICS BREAKTHROUGHS Lawrence Bell said last week he thought that the tempo of development leading to the use of nuclear fuels and anti-gravitational vehicles (he meant presumably ones that create their own gravitational field independently of the earth's) would accelerate. He added that the breakthroughs now feasible will advance their introduction ahead of the time it has taken to develop the turbojet to its present pitch. Beyond the thermal barrier was a radiation barrier, and he might have added ozone poisoning and meteorite hazards, and beyond that again a time barrier. Time however is not a single calculable entity and Einstein has taught that an absolute barrier to aviation is the environmental barrier in which there are physical limits to any kind of movement from one point in space-time continuum to another. Bell (the company not the man) have a reputation as experimentalists and are not so earthy as some of the other U.S. companies; so while this first judgement on progress with electrogravitics is interesting, further word is awaited from the other major elements of the air business. Most of the companies are now studying several forms of propulsion without heat engines though it is early days yet to determine which method will see the light of day first. Procurement will open out because the capabilities of such aircraft are immeasurably greater than those envisaged with any known form of engine. Aviation Report 15 July 1955 THERMONUCLEAR-ELECTROGRAVITICS INTERACTION The point has been made that the most likely way of achieving the comparatively low fusion heat needed - l,000,000 degrees provided it can be sustained (which it cannot be in fission for more than a microsecond or two of time) - is by use of a linear accelerator. The concentration of energy that may be obtained when accelerators are rigged in certain ways make the production of very high temperatures feasible but whether they could be concentrated enough to avoid a thermal heat problem remains to be seen. It has also been suggested that linear accelerators would be the way to develop the high electrical energies needed for creation of local gravitational systems. It is possible therefore to imagine that the central core of a future air vehicle might be a linear accelerator which would create a local weightless state by use of electrostatic energy and turn heat into energy without chemical processes for propulsion. Eventually - towards the end of this century - the linear accelerator itself would not be required and a ground generating plant would transmit the necessary energy for both purposes by wave propagation. Aviation Report 30 August 1955 POINT ABOUT THERMONUCLEAR REACTION REACTORS The 20 year estimate by the AEC last week that lies between present research frontiers and the fusion reactor probably refers to the time it will take to tap fusion heat. But it may be thought that rather than use the molecular and chemical processes of twisting heat into thrust it would be more appropriate to use the now heat source in conjunction with some form of nuclear thrust producer which would be in the form of electrostatic energy. The first two Boeing nuclearjet prototypes now under way are being designed to take either molecular jets or nuclear jets in case the latter are held up for one reason or another. But the change from molecular to direct nuclear thrust production in conjunction with the thermonuclear reactor is likely to make the aircraft designed around the latter a totally different breed of cat. It is also expected to take longer than two decades, though younger executives in trade might expect to live to see a prototype. Aviation Report 14 October 1955 ELECTROGRAVITICS FEASIBILITY Opinion on the prospects of using electrostatic energy for propulsion, and eventually for creation of a local gravitational field isolated from the earth's has naturally polarized into the two opposite extremes. There are those who say it is nonsense from start to finish, and those who are satisfied from performance already physically manifest that it is possible and will produce air vehicles with absolute capabilities and no moving parts. The feasibility of a Mach 3 fighter (the present aim in studies) is dependent on a rather large k extrapolation, considering the pair of saucers that have physically demonstrated the principle only a achieved a speed of some 30 fps. But, and this is important, they have attained a working velocity using very inefficient (even by to-day's knowledge) form of condenser complex. These humble beginnings are surely as hopeful as Whittle's early postulations. It was, by the way, largely due to the early references in Aviation Report that work is gathering momentum in the U.S. Similar studies are beginning in France, and in England some men are on the job full time. Aviation Report 15 November 1955 ELECTRO-GRAVITICS EFFORT WIDENING Companies studying the implications of gravitics are said in a new statement, to include Glenn Martin, Convair, Sperry-Rand, Sikorsky, Bell, Lear Inc. and Clark Electronics. Other companies who have previously evinced interest include Lockheed Douglas and Hiller. The remainder are not disinterested, but have not given public support to the new science - which is widening all the time. The approach in the U.S. is in a sense more ambitious than might have been expected. The logical approach, which has been suggested by Aviation Studies, is to concentrate on improving the output of electrostatic rigs in existence that are known to be able to provide thrust. The aim would be to concentrate on electrostatics for propulsion first and widen the practical engineering to include establishment of local gravity forcelines, independent of those of the earth's, to provide unfettered vertical movement as and when the mathematics develops. However, the U.S. approach is rather to put money into fundamental theoretical physics of gravitation in an effort first to create the local gravitation field. Working rigs would follow in the wake of the basic discoveries. Probably the correct course would be to sponsor both approaches, and it is now time that the military stepped in with big funds. The trouble about the idealistic approach to gravity is that the aircraft companies do not have the men to conduct such work. There is every expectation in any case that the companies likely to find the answers lie outside the aviation field. These would emerge as the masters of aviation in its broadest sense. The feeling is therefore that a company like A. T. & T. is most likely to be first in this field. This giant company (unknown in the air and weapons field) has already revolutionized modern warfare with the development of the junction transistor and is expected to find the final answers to absolute vehicle levitation. This therefore is where the bulk of the sponsoring money should go. Aviation Report 9 December 1955

APPENDIX II ELECTROSTATIC PATENTS [This following table has been retyped to fit this 60 column file format] [The report has the dates before the titles on the same line.] [All other formatting and spelling is exact.] ELECTROSTATIC MOTORS (a) American Patents still in force. 2,413,391 Radio Corp. America Power Supply System 20-6-42/31-12-46 2,417,452 Ratheon Mfg. Co. Electrical System 17-1-44/18- 3-47 2,506,472 W.B. Smits Electrical Ignition Apparatus 3-7-46Holl/ 2- 5-50 2,545,354 G.E.C. Generator 16-3-50/13- 3-51 (-Engl.P.676,953) 2,567,373 Radio Corp. America El'static Generator 10-6-49/11- 9-51 2,577,446 Chatham Electronics El'static Voltage Generator 5-8- 50/ 4-12-51 2,578,908 US-Atomic Energy C. El'static Voltage Generator 26-5-47/18-12-51 2,588,513 Radio Corp. America El'static High-Voltage Generator 10-6-49/11- 3-52 2,610,994 Chatham Electronics El'static Voltage Generator 1-9-50/16- 9-52 2,662,191 P. Okey El'static Machine 31-7-52/8 -12-53 2,667,615 R.G. Brown El'static Generator 30-1-52/26- 1-54 2,671,177 Consolidated Engg. Corp El'static Charging App's 4-9-51/2 - 3-54 2,701,844 H.R. Wasson El'static Generator of Electricity 8-1250/ 8- 2-55 2,702,353 US-Navy Miniature Printed Circuit Electrostatic Generator 17-7-52/15- 2-55 (b) British patents still in force. 651,153 Metr.-Vickers Electr.Co. Voltage Transformation of electrical energy 20-5-48/14- 3-51 651,295 Ch.F.Warthen sr. (U.S.A.) Electrostatic A.C. Generator 6- 8-48/14- 3-51 731,774 "Licentia" El'static High-Voltage Generator 19-9-52 & 21-11-52Gy/ 15- 6-55 (c) French patents still in force. 753,363 H. Chaumat Moteur electrostatique utilisant l'energie cinetique d'ions gazeux 19-7-32/13-10-33 . 749,832 H. Chaumat Machine electrostatique a excitation independante 24-1-32/29- 7-33 [This table has been retyped to fit this 60 column file format] [The report has the titles at the end of each line, w/ o ().] [All other formatting and spelling is exact.] The following patents derive from P. Jolivet (Algiers), marked "A" and from N.J. Felici, E. Gartner (Centre National des Recherches Scientifique - CRNS -) later also by R. Morel, M. Point etc. (S.A. des Machines Electrostatiques -SAMES-) and of Societe' d'Appareils de Controle et d'Equipment des Moteurs -SACEM-), marked "G " (because the development was centred at the University Grenoble. Mark of Application England America France Germany (Title) Applicant Date ----- -- ------- ------ ------- ------- --------- ------

----- G 8-11-44) 993,017 14- 8-45) 637,434 2,486,140 56,027 860,649 (Electrostatic Influence Machine G 17-11-44 639,653 2,523,688 993,052 815,667 (Electrostatic Influence Machine A 28- 2-45 912,444 (Inducteurs de Machines el'static) G 3- 3-45 643,660 2,519,554 995,442 882,586 (El'static Machines A 8- 6-45 915,929 (Machines electrocstatiques a flasques) A 16- 8-45 918,547 (Generatrice el'statique) G 20- 9-45) 998,397 21- 9-45) 643,664 2,523,689 837,267 (Electrostatic Machines) A 4- 2-46 923,593 (Generatrice el'statique) G 17- 7-46 643,579 2,530,193 1002,031 811,595 (Generating Machines) G 20- 2-47 671,033 2,590,168 (Ignition device) G 21-3 -47 2,542,494 655,474 Re-23,560 944,574 860,650 (El'static Machines) G 6- 6-47 645,916 2,522,106 948,409 810,042 (El'static Machines) A 16- 6-47 947,921 (Generatrice el'statique) G 16- 1-48 669,645 2,540,327 961,210 810,043 (El'static Machines) G 21- 1-49 669,454 2,617,976 997,991 815,666 (El'static Machines) G 7- 2-49 675,649 2,649,566 1010,924 870,575 (El'static Machines) G 15- 4-49 693,914 2,604,502 1011,902 832,634 (Commutators for electrical machine) G 9-11-49 680,178 2,656,502 1004,950 850,485 (El'static Generate) G 9-10-50) 702,494 2,675,516 1030,623 20- 2-51) (El'static Generate) G 29-11-50) 702,421 1028,596 20- 2-51) (El'static Generate) G 21-11-51 719,687 1051,430 F10421 (El'static Machines) G 20- 8-52 731,773 2,702,869 938,198 (El'static Machines) G 6-11-52 745,489 (El'static Generator) G 12- 2-53 745,783 (Rotating El'static Machines) G 8- 1-52 715,010 2,685,654 1047,591 (Rotating El'static Machines producing a periodical discharge.) Appl'n.No. ---------- G 27- 2-54 5726/55 (El'static Machines) G 8- 3-54 6790/ 55 (El'static Machines) G 28- 1-55 2748/56 (El'static Machines) NOTE:- ALL THE LISTED PATENTS ARE STILL IN FORCE "The Flying Saucer" The Application of the Biefield-Brown Effect to the Solution of the Problems of Space Navigation by Mason Rose, Ph.D., President University for Social Research (1952) Published in Science and Invention, August 1959, and Psychic Observer, Vol. XXXVII, No. 1 Documents Menu The scientist and layman alike encounter a primary difficulty in understanding the Biefeld-Brown effect and it's relation to the solution of the flying saucer mystery. A proper interpretation of this theory is prevented because both scientist and layman are conditioned to think in electromagnetic concepts, whereas the Biefeld-Brown effect relates to electrogravitation. Their lack of awareness is justifiable, however, because the data on electrogravitation, inasmuch as it is a comparatively recent and unpublished development, has limited availability and circulation. Townsend Brown, the discoverer of electrogravitational coupling, is the only known experimental scientist in this new area of scientific development as of this writing. Thus, anyone wanting to understand electrogravitation and its applications to astronautics must dismiss the principles of electromagnetics in order to grasp the essentially different principles of electrogravitation. Electrogravitational effects do not obey the known principles of electromagnetism. Electrogravitation must be understood as an entirely new field of scientific investigation and technical development. The most efficient method of effecting an understanding of electrogravitation is to review the evolutionary development of electromagnetism. From the smallest atom to the largest galaxy, the universe operates on three basic forces, namely Electricity, Magnetism and Gravitation. These forces can be represented as follows: Taken separately, these forces are of no real practical use. Electricity by itself is static electricity and therefore functionless. It will make your hair stand on end, but that is about all. Magnetism by itself has very few practical applications aside from the magnetic compass, and gravity simply keeps objects and people pinned to the earth. However, when they are used to work in combination with each other, almost endless technical applications come into being. Currently, our total electrical development is based on the coupling of electricity with magnetism, which provides the basis for the countless uses we make of electricity in modern societies. Faraday conducted the first productive empirical experiment with electromagnetism around 1830, and Maxwell did the basic theoretical work in 1865. The application of electromagnetism to microscopic and sub-microscopic particles was accomplished by Max Planck's work in quantum physics about 1890; and then in 1905 Einstein came forward with relativity, which dealt with gravitation as applied to celestial bodies and universal mechanics. It is principally out of the work of these four great scientists that our electrical developments, ranging from the simple lightbulb to the complexities of nuclear physics, have emerged. In 1923, Dr. Biefield, Professor of Physics and Astronomy at Dennison University and a former classmate of Einstein in Switzerland, suggested to his protoge, Townsend Brown, certain experiments which led to the discovery of the Biefield-Brown effect, and ultimately to the electrogravitational energy spectrum (in actuality, it was Brown who first observed the effect and brought it to the attention of Dr. Biefield, who suggest further experiments to determine the origin of and enhance the effect - Juniper). Biefield wondered if an electrical condenser, hung by a thread, would have a tendency to move when it was given a heavy electrical charge. Townsend Brown provided the answer. There is such a tendency. After 28 years of investigation by Brown into the coupling effect between electricity and gravitation, it was found that for each electromagnetic phenomenon there exists an electrogravitational analogue. This means, from the technical and commercial viewpoint, potentialities for future development and exploitation are as great or greater than the present electrical industry. When one considers that electromagnetism is basic to the telephone, telegraph, radio, television, radar, electric generators and motors, power production and distribution, and is an indispensable adjunct to transportation of all kinds, one can see that the possibility of a parallel, but different development in electrogravitation has almost unlimited prospects. The initial experiments conducted by Townsend Brown, concerning the behavior of a condenser when charged with electricity, had the characteristic of simplicity which has marked most other great scientific advancements. The first startling revelation was that if placed in free suspension with the poles horizontal, the condenser, when charged, exhibited a forward thrust toward the positive poles. A reversal of polarity caused a reversal of the direction of thrust. The experiment was set up as follows: The antigravity effect of vertical thrust is demonstrated by balancing a condenser on a beam balance and then charging it. After charging, if the positive pole is pointed upward, the condenser moves up. If the charge is reversed and the positive pole pointed downward, the condenser thrusts down. The experiment is conducted as follows: These two simple experiments demonstrate what is now known as the Biefeld-Brown effect. It is the first and, to the best of our knowledge, the only method of affecting a gravitational field by electrical means. It contains the seeds of control of gravity by man. The intensity of the effects is determined by five factors, which are: 1. The separation of the plates of the condenser, the closer the plates, the greater the effect. 2. The ability of the material between the plates to store the electrical energy in the form of elastic stress. A measure of this ability is called the "K" of the material. The higher the "K," the greater the Biefield-Brown effect. 3. The area of the plates, the greater the area giving the greater effect. 4. The voltage difference between the plates; more voltage, more effect. 5. The mass of the material between the plates; the greater the mass, the greater the effect. It is this fifth point which is inexplicable from the electromagnetic viewpoint and which provides the connection with gravitation. On the basis of further experimental work from 1923 to 1926; Townsend Brown in 1926, described what he called a "space car." This was a revolutionary method of terrestrial and extra-terrestrial flight, presented for experiment while motor propelled planes were yet in a primitive stage. This engineering feat by Townsend Brown was all the more remarkable when we consider such a machine produces thrust with no moving parts, does not use any aerodynamic principles of flight, and has neither control surfaces, or a propeller. Townsend Brown had discovered the secret of how the flying saucers fly years before and such objects were reported. Now the basic differences between electromagnetism and electrogravity have been described and the basic principles of the Biefield-Brown effect have been outlined, we are finally ready to understand the principles of astronautics or the conquest of space. The earth creates and is surrounded with a gravitational field which approaches zero as we go far into space. This field presses objects and people to the earth's surface; hence it presses a saucer object to the earth. However, through the utilization of the Biefield-Brown effect, the flying saucer can generate an electrogravitational field of its own which modifies the earth's field. This field acts like a wave, with the negative pole at the top of the wave and the positive pole at the bottom, the saucer travels like a surfboard on the incline of a wave that is kept continuously moving by the saucer's electrogravitational generator. Since the orientation of the field can be controlled, the saucer can thus travel on its own continuously generated wave in any desired angle or direction of flight. Since the saucer always moves towards its positive pole, the control of the saucer is accomplished by varying the orientation of the positive charge. Control, therefore, is gained by switching charges rather than by the control surfaces. Since the saucer is traveling on the incline of a continually moving wave which it generates to modify the earth's gravitational field, no mechanical propulsion is necessary. Once we understand that the horizontal and vertical controls are obtained by shifting the positive pole which turns the field, then we are in a position to extrapolate a finished saucer design. The method of controlling the flight of the saucer is illustrated by the following simple diagrams showing the charge variations necessary to accomplish all directions of flight. The saucer's edge would contain a number of conductor segments, and the saucer would turn in any direction simply by shifting the positive and negative charges to appropriate positions along its edge. The vertical thrust would be regulated by varying the charge on top of the saucer, the amount of thrust being regulated by the amount of charge generated. In all probability, flying saucers do not utilize external controls for direction, nor do they have any visible means of propulsion. Flying saucers travel using the Biefield-Brown electrogravitational effect, and hence do not utilize any of the standard aerodynamic principles of an airfoil. Flying saucers cannot be understood from the traditional principles of aeronautical engineering; however, the older points of view are useful for critical theoretical analysis and empirical testing. Before UFO's were ever seen and validly reported, Townsend Brown developed a captive flying saucer - a scale model saucer with a free bearing going around a stationary pole. Brown did not start with round objects, in fact, the first object that he flew was a triangle, the next a square, then a square with the edges cut off, and finally a round shaped saucer. Eventually, experiments proved the saucer shape most effective. Changes were made for empirical reasons. Having solved the problem of horizontal thrust, Townsend Brown developed a profile shape which would be most efficient to navigate the electrogravitational field for maximum vertical thrust. The final profile that developed was the shape illustrated here: The first report of a disc-shaped object in the sky dates back to the sixteenth century. At long intervals during the centuries since then have come other reports. Most of them are undoubtedly unreliable as observations, distorted by telling and retelling. But in these older reports, as well as in the very numerous series which has accumulated since 1947, there is a teasing common thread concerning appearance and behavior which makes any certainties about the unreality of flying saucers very insecure. One of the great difficulties in substantiation of these reports is that, in both appearances and behavior, these objects seem to be simple scientific impossibilities. Here are some of the reasons advanced by technical men to prove the impossibility of devices such as the reports describe: 1. The reports reveal, in most cases, no method of propulsion which can be understood. There are no propellers in any of the reports. Some of the reports describe a long flame jet trailing behind a cigar shaped object. But this flame is orange-red in color, indicating an inefficient combustion which would make it ineffective as a reaction jet such as propels rockets and jet planes. No other known physical laws seemed capable of explaining the observed motion of the objects. 2. The reports describe a range of speed and acceleration from stationary hovering to speeds greater than present day rockets can deliver, and the changes of rate of motion, the accelerations, are far beyond the capacities of any known man-made vehicles. Flight experts point out that such accelerations would impose impossible stresses on any human or human like occupants. therefore, they say, the reports must be false or erroneous. many of the reports concern night sightings and describe a glow, usually of blue or violet color, around a periphery of the objects. Physicists have noted that such a glow is characteristic of a very high voltage electrical discharge, but add that this suggests no means of explaining the appearance or behavior of the objects described in the reports. 4. The description of shapes and performance seems to indicate a complete or almost complete disregard of aerodynamic principles. The objects seem not to need the support of air as a plane does, nor to depend on the lift provided by properly designed surfaces moved rapidly through an air medium. These are weighty arguments PROVIDED THE ASSUMPTIONS BEHIND THEM ARE CORRECT. As I have previously indicated, the observed motion of condenser has been labeled the Biefield-Brown effect. Studying this effect, Brown pointed out in 1923 that this tendency of a charged condenser to move might easily grow into a new and basically different method of propulsion. By 1926 he had described a "space car" utilizing this new principle. By 1928 he had built working models of a boat propelled in this manner. By 1938 he had shown that his specially designed condensers not only moved, but had certain interesting effects on plants and animals. All of this, while very exciting, is for most of us just a repetition and reinforcement of the rapid scientific development so characteristic of our age. But then came the unexpected Townsend Brown, working in his laboratory, building models and trying endless variations in size, shape and design of his charged condensers, made a flying saucer which flew around a maypole, before flying saucers became a newspaper topic. And the reasons listed above, which led the specialists to reject the reports of observed saucers, proved to be both explicable and necessary to their operation under the electrogravitational principle. Let us look at the four main objectives in a new light: 1. No understood method of propulsion. The saucer made by Brown have no propellers, no jets, no moving parts at all. They create a modification of the gravitational field around themselves, which is analogous to putting them on the incline of a hill. They like a surfboard on a wave. he surfboard moves without propellers or jets to, but it is confined to the direction and speed of the water wave. The electrogravitational saucer creates its own "hill," which is a local distortion of the gravitational field, then it takes this "hill" with it in any chosen direction at any rate. 2. The second objection concerned the tremendous accelerations which on the basis of previous technology, would subject any animal occupants to unbearable stresses. But, says Brown, the occupants of one of his saucers would feel no stress at all, no matter how sharp the turn or how great the acceleration. This is because the ship and all the occupants and the load are all responding equally to the wavelike distortion of the local gravitational field. In an airplane the propeller pumps air backward and, by reaction, the plane moves forward. The reaction thrust on the propeller is transferred to the frame of the aircraft. This frame then shoves the load and occupants forward *contrary to their natural tendency to move at a constant rate in a constant direction*. But in the saucer no such transfers of thrust from one member to another occurs. The entire assembly moves in unison in response to the locally modified gravitational field. The nearest analogy in our experience is going down in an elevator. When the elevator starts down, it is not necessary for the elevator to shove on our bodies, both elevator and passengers share a gravitational tendency to move down. They do so without and shoving or any stresses between elevator and passengers. 3. Townsend Brown's saucers require a highly charged leading edge - the positive pole. But such a charged pole produces an electrical corona. In the largest models made, this develops a decided bluish-violet glow easily in the darkness or a dim light. A full scale ship operating on this principle would be expected to produce a spectacular corona effect visible for many miles. 4. The outlines and shape of Brown's saucers were the result of electrogravitational considerations, not the result of wind tunnel tests of aerodynamic designs. For they move, not on the lift of air, but on the lift of a modified gravitational field. In operating flying saucers such aerodynamic considerations would have to be taken into account to reduce drag and friction, but not to produce lift and thrust. 5. And, finally, when Brown turned his attention to improved ways of generating high voltages, the most promising new method involved the use of a flame jet to convey negative charges astern. This flame was relatively inefficient as a generator if it was adjusted for the best combustion of the fuel. But if it was adjusted to an orange-red color, indicating incomplete combustion of fuel, it conveyed the charges very effectively and set up the required negative space charge behind the ship. The reasons advanced by the experts to "explain away" the saucer reports, when seen from a new and different viewpoint appear to be the specific reasons why they can operate, on electrogravitational rather than electromagnetic principles. The next opinion which must be corrected is the idea of overly intensified supersonic vibration. The Townsend Brown experiments indicate that the positive field which is traveling in front of the saucer acts as a buffer wing which starts moving the air out of the way. This immaterial electrogravitational field acts as an entering wedge which softens the supersonic barrier, thus allowing the material leading edge to enter into a softened pressure area. Diagramed, this would be illustrated as follows: It should be noted that in a jet plane or guided missile the extra weight added to create the Biefield-Brown electrogravitational effect would be compensated for by the added thrust created by the movement of the plane toward the positive field created in front of the leading edge. As we have previously stated, for every known electromagnetic effect there is an analogous electrogravitational effect but electrogravitational applications and results differ from those of electromagnetic. This presupposes that an entire new electrogravitational industry comparable to the present electromagnetic industry will emerge from the theoretical formulations and empirical experiments of Townsend Brown. INDEXED: BROWN United States Patent Office 3,187,206 Patented June 1, 1965

3,187,206 ELECTROKINETIC APPARATUS Thomas Townsend Brown, Walkertown, N.C., assigner, by mesne assignments, to Electrokinetics, Inc., a corporation of Pennsylvania Filed May 9, 1958, Ser. No. 734,342 23 Claims (Cl. 310-5) This invention relates to an electrical device for produc- ing a thrust by the direct operation of electrical fields. I have discovered that a shaped electrical field may be employed to propel a device relative to its surroundings in a manner which is both novel and useful. Mechanical forces are created which move the device continuously in one direction while the masses making up the environment move in the opposite direction. When the device is operated in a dielectric fluid me- dium, such as air, the forces of reaction appear to be present in that medium as well as on all solid material bodies making up the physical environment. In a vacuum, the reaction forces appear on the solid environmental bodies, such as the walls of the vacuum chamber. The propelling force however is not reduced to zero when all environmental bodies are removed be- yond the apparent effective range of the electrical field. By attaching a pair of electrodes to opposite end of a dielectric member and connecting a source of high elec- trostatic potential to these electrodes, a force is produced in the direction of one electrode provided that electrode is of such configuration to causethe lines-of-force to con- verge steeply upon the other electrode. The force, there- fore, is in a direction from the region of high flux density toward the region of low flux density, generally in the direction through the axis of the electrodes. The thrust produced by such a device is present if the electrostatic field gradient between the two electrodes is non-linear. This non-linearity of gradient may result from a difference in the configuration of the electrodes, from the electrical potential and/or polarity of adjacent bodies, from the shape of the dielectric member, from a gradient in the density, electric conductivity, electric permittivity and manetic permeability of the dielectric member or a com- bination of these factors. A basic device for producing force by means of elec- trodes attached to a dielectric member is disclosed in my Patent 1,974,483. In one embodiment disclosed in my patent, an electrostatic motor comprises devices having a number of radially directed fins extended from one end of the dielectric body and a point electrode on the oppo- site end of the dielectric body. When this device is sup- ported in a fluid medium, such as air, and a high electro- static potential is applied between the two electrodes, a thrust is produced in the direction of the end to which the fins are attached. Other electrostatic devices for producing thrust are dis- closed and described in detail in my British Patent 300,- 311, issued August 15, 1927. Recent investigations in electrostatic propulsion have led to the discovery of improved devices for producing thrust by the use of electrical vectorial forces. Accordingly, it is the primary object of this invention to provide an improved electrical device for producing thrust. It is another object of this invention to provide a device for producing modulated thrust in response to varying electrical signals, which device produces a greater effect than the prior type devices mentioned above. It is another object of this invention to provide a device which shapes or concentrates electrostatic flux to produce an improved thrust. Broadly, the invention relates to shaping an electrical field to produce a force upon the device that shapes the field. The electrical field is shaped by the use of an elec- trode of special configuation whereby the electric lines- of-force are made to converge at a distance from the electrode. One illustrative embodiment of this invention which satisfies the above requirement is an arcuate sur- face, or alternatively, a system of wires, tubes or plates embedded in a dielectric surface and forming a directive array. One such highly-charged electrode electrode acting within and upon an ambient of differential electrical potential will move in response to the forces created by shaping of the electrostatic field. If a smaller electrode is added at or near the focus of the field-shaping electrode, and mech- chanically attached to that electrode, both electrodes as a system will move in a direction of the larger or field-shaping electrode. As is mentioned above, the field-shaping electrode alone, when charged with respect to its electric ambient, will move or possess a force in the direction of its apex. If another electrode carrying a different charge is added at or near the focal point of the field- shaping electrode, then the field becomes more concentrated, i.e. shaped to a greater degree and the resulting thrust is greater that that which exists when the field-shaping elec- trode alone is employed. Briefly in accordance with aspects of this invention, an electrode is connected on each end of a dielectric mem- ber and one of the electrodes defines a large area flat or preferably arcuate surface which is curved in such a direc- tion to produce, usually in co-operation with the other electrode, a shaped electrostatic field. Advantageously, if the arcuate electrode is in the form of a parabola or hyperbola, the length of the dielectric member may be such that the other electrode is located in the region of the focus of the parabola or hyperbola, as the case may be. If the arcuate electrode is hemispherical, the other electrode is located near the center of the hemi- sphere. In accordance with other aspects of this invention the dielectric member supporting the two electrodes may have electrical conductivity and/or dielectric constant which varies progressively between its ends so that the dielectric member contributes to the non linearity of the fiel gradi- ent and causes a greater thrust to be developed. In accordance with still other aspects of this invention, an annular electrode member is secured to an electrode mounted in the region of the axis of the annular electrode. If the second electrode is located at the center of the an- nular electrode and the two electrodes are energized, such force is not detected. However, if the second or innermost electrode is displaced from the center of the annular electrode in the region of the axis of the annular electrode and the electrodes are energized, then thrust will be produced by the two electrodes. The annular electrode may either be a flat ring, a toroid, or a section of a cylinder. In accordance with still other aspects of this invention, tapered dielectric members having electrodes secured to opposite edges thereof may be employed to produce a thrust in response to the application of potentials to these electrodes. The thrust produced by these tapered dielectric members maybe further augmented by em- bedding massive particles, such as lead oxide, in the wedges, which particles are usually more concentrated near the points of the wedges. Accordingly, it is a feature of this invention to provide an electrical device for producing thrust which includes a dielectric member and electrodes supported at each end of the dielectric member, one of which electrodes is located in the region of the focal point of the arc of the arcuate surface electrode. It is another feature of this invention to provide a device for producing thrust having a dielectric member and a pair of electrodes secured to opposite ends of the dielectric rod or member, one of which electrodes de- fines a parabolic or hyperbolic surface, the other elec- trode being located in the region of the focus of said surface. It is another feature of this invention to employ an insulating rod or member between the two electrodes, which rod or member has a varying dielectric constant, said dielectric constant progressively increasing or decreasing along the length of the dielectric member. It is still another feature of this invention to employ a rod or member connected between the two electrodes across which an electrostatic potential is applied, which rod or member has a varying electrical conductivity, said con- ductivity progressively increasing or decreasing along the length of the dielectric member. It is another feature of this invention to employ a single electrode having an arcuate surface and to connect a source of potential to the arcuate surface which is op- posite in polarity to the potential of the masses compris- ing the environment of the arcuate surface. It is still a further feature of this invention to employ an arcuate electrode as a device for producing thrust and to apply a varying electrical signal to the arcuate elec- trode. It is still another feature of this invention to employ a wedge of dielectric material having electrodes on op- posite ends thereof to produce a thrust in response to the application of electrical potentials. It is still a further feature of this invention to employ a tapered dielectric material having massive particles em- bedded therein to produce a thrust in response to the application of potentials to the electrodes secured to the dielectric member. It is still a further feature of this invention to employ an annular ring electrode and a second electrode secured to the annular electrode in the region of the axis of the annular electrode in the region of the axis of the ennular electrode to produce a thrust in responnse to the application of electrical potentials thereto. These and other various objects and features of this invention will be apparent from consideration of the following description when read in connection with the accompanying drawing wherein: FIGURE 1 is a view in elevation of one illustrative embodiment of this invention; FIGURE 2 is a view in elevation, partly in section, of another illustrative embodiment of this invention; FIGURE 3 is a graphical representiation of the field gradient between the electrodes of one illustrative example of this invention in which distance from one electrode is plotted as the abscissa whereas flux density is plotted as the ordinate; FIGURE 4 is a perspective view of another illustrative embodiment of this invention; FIGURE 5 and 6 are perspective views of still another illustrative embodiment of this invention; FIGURE 7 is an end view of another illustrative em- bodiment of this invention employing a pair of devices of the type disclosed in FIGURE 6, which devices are mounted and serially connected in a single array; FIGURES 8A, 8B and 8C are views in elevation, partly in section, of still other illustrative embodiments of this invention. Referring to FIGURE 1, there is depicted an insulating member 10 having an arcuate electrode 12 mounted on one end thereof and a second electrode 14 mounted on the opposite end thereof. A source of direct current voltage 13 is connected to electrodes 12 and 14 through conductors 15 and 17, respectively. I have dis- covered that if two electrodes are mounted on opposite end of a dielectric member, and a field emanates from these electrodes which produces a linear gradient through the dielectric member as shown by the dotted line 30 of FIGURE 3, then no thrust is produced by the dielectric member. However, if the field is distorted to produce a non-linear gradient such as graphically represented by line 32 in FIGURE 3, then a thrust will be produced, which thrust will be related to the degree of non- linearity of the field gradient. One way to produce a gradient which varies non linearly is to shape one of the electrodes in a form of an arcuate surface such as 12. However, numerous other ways to influence the field gradient will be disclosed below. Electrode 14 represents a substantial mass and it has been found that best results are obtained if the surface area of electrode 14 is greater than the surface area of the end of rod 10. In one particular ex- ample, a spherical electrode having a diameter greater than the diameter of rod 10, produced very satisfactory results. Advantageously, the dielectric member 10, may be employed to increase the non-linearity of the field gradient. For example, the dielectric member may be of material having a uniform relative dielectric constant and be tapered in the direction of electrode 14 such that the member 10 in the region of electrode 12 has a much greater cross-sectional area than the end of member 10 which is connected to electrode 14. An equivalent re- sult may be obtained if the member 10 is of uniform diameter but has a dielectric of graduated density or which comprises a material having a progressively dif- ferent electrical conductivity or dielectric constant, or alternatively the electrical conductivity, varies from a low value in the region of electrode 14 to a high value in the region of electrode 12. The arcuate electrode 12 may be either a stitched wire surface or a solid conducting surface. In the case of stitched wire surface, the wires are very close together so that when an electrical potential is applied to these wires, they act substantially in the same manner as a conductive surface. Arcuate electrode 12 will produce a thrust when a potential is applied to the electrode 12 which is opposite in polarity to the potential of the bodies in the region of electrode 12. Such a thrust will be pro- duced even though the dielectric member 10 and the electrode 14 are eliminated from the structure. How- ever, the thrust produced bye the charged arcuate elec- trode 12 when actuating alone is less than the thrust produced by the combined device, that is, employing the dielectric member 10 and the oppositely charged elec- trode 14. Referring now to FIGURE 2, there is depicted another illustrative embodiment of this invention in which field- shaping is accomplished. In the embodiment of FIGURE 2, the planar electrode 18 is connected to a hemispherical electrode 14 by means of a dielectric rod 10. When a source of electrical potential (not shown) is connected through wires 15 and 17 to electrodes 18 and 14, respec- tively, a field gradient will be produced between elec- trodes 18 and 14, which field gradient varies in accord- ance with the graph represented by the solid line 32 of FIG- URE 3. In this particular embodiment, as well as in the embodiment of FIGURE 1, the non-linearity of the field gradient is further augmented by the use of a con- necting rod 10 which is a dielectric with progressively different dielectric constant between electrodes 18 and 14. A similar result may be produced by the use of a rod 10 having electrical conductivity which varies progres- sively between electrodes 18 and 14. Referring now to FIGURE 4 there is depicted still another illustrative embodiment of this invention in which a thrust is produced in response to the application of electrical potentials. A frusto-conical surface 25 comprising a metal or hav- ing a metal surface to be used on an electrode is con- nected to a tapered member 27. The tapered member 27 is frusto-conical and is primarily of non-conductive ma- terial but contains granules of semi-conducting material, which granules are concentrated neat the tip 28. Mounted on tip 28 is a half-wave radiator 29 which may be in the form of a disk. It is noted that the axis of member 27 coincides with the axis of member 25. When a source of potential is connected to electrodes 25 and 29, a thrust is produced in the direction of the arrow 31 regardless of the polarity of the applied voltage. How- ever, a greater thrust is produced if the electrode 25 is positive with respect to electrode 29. Alternating current voltages may also be applied to electrodes 25 and 29 and the potential may be either superimposed upon or substi- tuted for the direct current voltages. Preferably, the frequency of the applied A.C. voltage is such that the di- ameter of the disk 29 constitutes a half-wavelength of the applied voltage. Referring now to FIGURE 5 there is disclosed a tapered member 32 which is non-conductive material and may contain particles of semi-conducting material in a manner similar to member 27. The semi-conducting material contained in member 32 and in member 27 may be any convenient form of massive particles such as lead oxide. Along one surface of member 32 is an electrode 34 while along the opposite surface is another electrode 36. When a potential is applied to these electrodes, preferably of a polarity such that electrode 36 is positive with respect to electrode 34, a thrust is produced in the direction of the arrow 37. In the devices disclosed in both of FIGURES 4 and 5, the thrust produced by the electrodes is aug- mented by the varying cross-sectional area of the non- conductive member connecting the electrodes and is fur- ther augmented by the voltage gradient produced by the embedded particles, which voltage gradient is greater than that which would be introduced by a tapered non-conductive member without embedded particles. Referring now to FIGURE 6 there is depicted a bank of members 32 such as disclosed in FIGURE 5 in which like electrodes 36A through 36E are secured together by a connector in any convenient form, such as plate 38. Each of these members 32A through 32E produces a thrust in the direction of the arrow 37A and the resultant force is equal to the sum of the thrust produced by the individual members 32 in response to the application of potentials to the electrodes 34A-34E and 36. In FIGURE 7 there is depicted a pair of banks of mem- bers, such as depicted in FIGURE 6, in which the elec- trodes are serially connected. In this particular instance, a plate or other member 40 comprises an electrode on which are mounted an array of members 32F through 32J. A second electrode 42 is secured between electrodes 32F through 32J and electrodes 32K through 32P. A third electrode 44 is connected to the electrode 34 on each of members 32K through 32P. It is to be noted that electrodes 40 and 44 are connected to a source of one potential while electrode 42 is connected to a source of the opposite potential. The thrust produced by this array is in the direction of arrow 37B and the manner in which this thrust is produced is similar to that explained in con- nection with FIGURES 5 and 6, although it would appear that electrode 42 will experience a natural attraction for electrodes 40 and 44. A non-linear field gradient is pro- duced between these electrodes by the varying cross-sectional area of members 32 and by the presence of semi-conducting particles in members 32. This non-linear field gradient gives rise to the thrust, as mentioned above. Referring now to FIGURES 8A, 8B and 8C there is depicted other illustrative embodiments of this invention. In FIGURE 8A a toroid member 43 has an electrode 50 supported at its center by means of insulating rod 52. If the electrode 50 and the toroid member 43 are both con- ducting surfaces defining electrodes and these electrodes are connected to sources of opposite potential, no thrust will be developed by the device. If, however, as depicted in FIGURE 8B electrode 50 is translated along the axis of generation of toroid or annular member 48 and again supported by non-conductive members 52, this device will experience a downward thrust, as indicated by arrow 53, in response to the application of potentials of either polarity. It is believed that this force is produced by the annular configuration of electrode 48 and the off central location of electrode 50. In the instance of FIG- GURE 8C, electrode 50 is positioned beneath the center of electrode 48 and positioned on the axis of generation of electrode 48. When potentials are applied to electrodes 48 and 50 in FIGURE 8C, a thrust is produced in an up- ward direction, as indicated by arrow 54. Here again the field gradient is produced by the configuration of electrode 48 and the location of electrode 50 with respect to elec- trode 48. From the foregoing discussion, it is also apparent that a combination of a curved electrode, a supporting member of varying cross-sectional area, and a second electrode supported bye the connecting member will produce a thrust along the axis of the curved electrode when potentials are applied to the electrodes. Similarly, a thrust may be de- veloped between plane electrodes of unequal areas which are connected by a member of varying cross-sectional area. The thrust developed by this last mentioned device is further increased by the introduction of semi- conduc- tive particles in the non-conducting member, which par- ticles are more concentrated in the region of the smaller electrode than in the region of the larger electrode. Fur- ther, these tapered members having planar electrodes con- nected to opposite surfaces may be stacked in vertical ar- rays and connected in parallel, or they may be stacked in vertical arrays connected in series with similar vertical arrays. In applying potentials to these various embodiments, it has been found that the rate at which the potential is applied often influences the thrust. This is especially true where the dielectric members of high dielectric constant are used and the charging time is a factor. In such cases, the field gradient changes as the charge is built up. In such cases where initial charging currents are high, dielectric materials of high magnetic permeability like- wise exhibit thrust with time. One advantageous manner of applying potential is that of employing potentials which vary cyclically. It is thus apparent that one embodiment of this inven- tion embodies a pair of electrodes mounted on an insulat- ting member, one of which electrodes defines an arcuate surface to produce an improved thrust in response to the application of direct current potentials. It is also apparent that this thrust is augmented by increasing the non- linearity of the field gradient by a progressively-changing characteristic of the dielectric member connecting these electrodes. This non-linearity of field may be produced by a gradient in electric conductivity, electric permittivity and/or magnetic permeability along the length of the \ member, or it may result from a change in the cross- sectional area of the rod which rod ahs otherwise uniform characteristics. While I have shown and described various embodiments of my invention, it is understood that the principles there- of my be extended to many and varied types of machines and apparatus. The invention therefore is not to be limited to the details illustrated and described herein. I claim: 1. A device for producing thrust comprising a field shaping surface formed of stitched, closely spaced con- ductors and having a dielectric material therebetween to define a smooth surface, a dielectric member connected to said field shaping surface and an electrode on the end of said dielectric member remote from said field shaping surface and means for applying electrical potential be- tween said electrode and said closely spaced conductors. 2. A device for producing thrust in accordance with claim 1 wherein said dielectric member has a dielectric constant which varies progressively between said electrode and said surface means. 3. A device for producing thrust comprising an elec- trode having a relatively large surface area, an electrode 7 positioned in the region of the axis of generation of said surface and having a relatively small surface area, di- electric means connecting said electrodes and means for applying a varying electrical potential to said electrodes. 4. A device in accordance with claim 3 wherein said dielectric means exhibits a dielectric constant which varies progressively from a relatively high value in the region of the large electrode to a relatively low value in the region of said small electrode. 5. A device in accordance with claim 3 wherein said dielectric means has an electrical conductivity which varies progressively between said electrodes. 6. A device for producing thrust comprising a planar electrode, a second electrode positioned in the region of the axis of generation of said planar electrode and having a surface area smaller that the surface area of said planar electrode, a dielectric member connecting said electrodes and means for applying a high electrostatic potential to said electrodes. 7. A device in accordance with claim 6 wherein said dielectric member is tapered from the planar electrode towards the smaller electrode. 8. A device in accordance with claim 6 wherein said dielectric member has a conductivity which varies pro- gressively from a relatively high value near the planar electrode to a relatively low value near the smaller elec- trode. 9. A device for producing thrust in response to the ap- plication of electrical potentials to the electrodes thereof comprising a first electrode, a second electrode having a relatively large planar surface area with respect to said first electrode and means including a connecting member supporting said electrodes in spaced relationship for pro- ducing a varying field gradient between said electrodes. 10. A device in accordance with claim 9 wherein said connecting member has a varying cross-section. 11. A device in accordance with claim 9 wherein said connecting member tapers between said electrodes. 12. A device in accordance with claim 9 wherein said first and second electrodes are flat electrodes of unequal area. 13. A device according to claim 9 including means for applying a varying electrical potential to said electrodes. 14. A device in accordance with claim 9 wherein said connecting member has a dielectric constant which varies between electrodes. 15. A device in accordance with claim 14 wherein said first electrode is a frusto-conical surface and wherein said connecting member extends along the axis of generation of said first electrode. 16. A device in accordance with claim 14 wherein said first electrode defines a frusto-conical surface. 17. A device in accordance with claim 9 wherein said connecting member comprises semi-conducting particles whereby said connecting member is given a conductivity gradient. 18. A device in accordance with claim 15 wherein said second electrode is a disk-shaped radiator and wherein the potentials applied to said electrodes are alternating current potentials, the diameter of said disk-shaped elec- trode being equal to a half-wave length of the alternating current potential. 19. A device in accordance with claim 15 wherein said connecting member contains semi-conducting particles which are more concentrated in the region of the disk radiator than in the region adjacent said first electrode. 20. A device for producing thrust in response to the application of electrical potentials to the electrodes there- of comprising an annular electrode, a second electrode, and insulating means connecting said electrodes whereby thrust is produced along the axis of generation of said annular electrode in response to the application of electri- cal potentials thereto. 21. A device in accordance with claim 20 wherein said annular electrode comprises a toroidal surface. 22. A device in accordance with claim 20 wherein said second electrode is mounted on the axis of generation of said annular electrode. 23. A device in accordance with claim 22 wherein said second electrode is displaced from the center of said an- nular electrode whereby a thrust is developed along said axis in a direction from said second electrode towards that annular electrode in response to the application of elec- trical potentials thereto. References Cited by the Examiner

United States Patents 1,974,483 9/34 Brown ______________________ 310-5

Foreign Patents 1,003,484 11/51 France Milton O. Hirshfield, Primary Examiner. Oris L. Rader, David X. Sliney, Examiners. Research and Preliminary Engineering Space Vehicle Program **Subject**: Research and Preliminary Engineering for Space Vehicle Program Part I - Propulsion Part II - Navigational and Flight Control Instruments Part III - Communication and Remote Control Systems Part IV - Materials of Construction

Synopsis

This proposal recommends a long-range coordinated program for the research and preliminary engineering leading to the construction of prototype space vehicles. The proposal stresses the importance of research on gravitation and on the relationships between electrodynamics and gravitation. It calls attention to certain possibilities inherent in such a program of development. The program would be divided and conducted in steps, as follows: (a) Preliminary investigations of physical methods, (b) Engineering development, (c) Advance design, (d) Construction of operating prototypes.

Scope Of Interest

(a) Propulsion The program anticipates the use of electric methods of propulsion and control, and specifically excludes the consideration of jet or rocket propulsion devices, per se, except as a means for generating the required high electrical potential. Emphasis is placed on studies of the physical relationships between electrodynamics and gravitation leading to the development of methods of electrogravitic propulsion and steering control. (b) Navigational and Flight Control Instruments Problems of space navigation are to be examined, particularly with the view of applying electrogravitic principles in the design of flight instruments to indicate: 1. Gravitational Vector (insensitive to acceleration), 2. Acceleration (insensitive to gravity), 3. Gravitational Gradient (insensitive to acceleration), 4. Gravitational Potential of Space, 5. Electrical Potential of Space, 6. Space Speed (absolute ether drift). (c) Communication and Remote Control Systems Applications of electrogravitic induction to communications and remote control are to be developed. Use of gravitational radiation is the objective. Basic tests with electrically-shielded capacitors and massive high-K dielectrics are proposed. Methods are to extended into full-scale communication systems. Such systems, while similar to electromagnetic (radio) systems may be found to offer many advantages - such as higher penetrability, elimination, elimination of "shaded" areas, higher velocity of wave propagation and a wholly new spectrum of channels. (d) Materials of Construction Continuation of the research of the late Charles Francis Brush on the "non-equivalence of mass and weight" is recommended (see appendix). Further confirmation of the Brush findings may be provided by the existence of gravitational isotopes, as distinguished from mass isotopes. Procedures for isolating gravitational isotopes in common aircraft metals, with the object of creating super-light alloys. Methods of beneficiation are suggested for enriching the content of lighter gravitational isotopes in common aircraft metals, with the object of creating super-light alloys. The spontaneous evolution of heat, observed by Brush and Harrington, appears to be one of the characteristics of lighter gravitational isotopes, and may serve as a tracer in the steps of beneficiation. Studies are proposed to determine the source of the energy and to investigate possible uses of said heat. This program is to include a study of the rare earth metals and their alloys, and also the metal tantalum, regarded as potential aircraft materials. In nature, most of the rare earth metals (and tantalum) indicate mean values of specific gravity having large negative anomalies, and this property makes them interesting as probable rich sources of gravitational isotopes required in the manufacture of super-light materials of construction.

Program Of Research And Development

Group A - Electrodynamic- Gravitational Field Relationships
Purpose: Generation of quasi-gravitation by electrical means, quantitative measurements and derivation of equations. Abstract: One of the basic relationships between the electrodynamic field and the gravitational field appears to be revealed "during the process of charging or discharging electric capacitors". Proposal: Confirming experiments are proposed in which two or more large high-voltage capacitors are associated spatially with a short-period geophysical gravimeter. Careful observations are to be made of the momentary gravitational anomalies induced in the region which accompany the change in electrical state. Studies are proposed of the effects of varying total capacitance, rate-of-change of electric charge, mass of dielectric materials, specific inductive capacity of said materials and whether the effects are vector or scalar. These investigations shall be directed toward the derivation of a satisfactory mathematical expression including all of the above factors.

Group B - Propagation Of Gravitational Waves
Purpose: Transmission and reception of electro-gravitational waves for purposes of communication and remote control. Abstracts: Preliminary experiments have indicated the existence of an inductive inter-action between two independent shielded capacitors. In these experiments, a discharging capacitor induces a voltage in an adjacent capacitor, and the effect appears to penetrate electromagnetic shielding. Theoretically, this effect of one capacitor upon another appears to be electrogravitic in nature and constitutes evidence of a new type of wave propagation. It is believed that this form of inductive transmission may eventually be utilized in a completely new method of wireless communication. Proposal: It is proposed that progressively larger-scale and longer-range transmissions be conducted. Beginning with untuned systems, laboratory tests are proposed to explore the basic electrogravitic relationships between simple systems of capacitors. Then, progressing to tuned systems, and pulsed (radar) applications, large- scale out-of-door demonstrations are suggested. Such demonstrations shall be conducted between suitably protected transmitting and receiving vaults (preferably underground) which are thoroughly shielded against electromagnetic radiation. Appropriate studies of wave attenuation due to transmission through large masses of earth may then be undertaken. Similar studies of wave attenuation in sea water are also prosed. These studies are to be supported by fundamental research on the nature of electrogravitic induction (See appendix for outline).

Group C - Ponderomotive Forces In Solid Dielectrics
Purpose: Isolation and measurement of electrogravitic forces in solid dielectrics. Abstract: Investigations conducted by Biefeld and Brown point to the existence of a hitherto unrecognized ponderomotive

force in all ferroelectrics under changing electric stress. This force appears to be a function of the specific inductive capacitance and the mass of the dielectric material, as well as high voltage and current factors. Recent availability of the massive barium titanate (high-K) dielectrics and other dielectrics of this class give promise of developing these forces to the point where they may become of practical importance in specific propulsion applications. Proposal: A survey of dielectric materials revealing this effect is proposed. Beginning with a critical analysis, using the Townsend Brown Differential Electrometer (an instrument developed at the Naval Research Laboratory and at the University of Pennsylvania), studies are proposed of the forces developed in mica, glass, marble, phenolics and dielectrics in general and then, in particular, the newer ceramic dielectrics. This work is to be augmented by basic determinations of the Biefeld-Brown effect in vacuum. (See appendix). It is proposed that, after suitably active materials are selected, scale models of other rotary and linear "motors" be constructed and tested. With the necessary engineering data then at hand, a motor to weigh approximately 500 lbs. may be constructed to propel a model ship. This is proposed as a practical demonstration of one of the forms of electrogravitic drive. Ether drift and space-couple observations, including specifically a repetition of the classic Trouton-Noble experiment (but using massive dielectrics) are suggested as being of interest not only for their contribution to basic knowledge of the nature of space but as bearing upon the principle of operation of space speed indicators (See appendix). Low temperature experiments in physics of the solid state (using the liquid-helium cryostat) are highly recommended but are expensive. These experiments, however, may be so designed as to provide answers to many questions relative to the fundamental nature of gravitation. They are to embrace such subjects as the "Anomalous Mass of the Electron in Metals" and the "Behavior of Super-Cooled Dielectrics". The availability of the liquid-helium cryostat would enable the project to engage continuously in low-temperature work which could contribute enormously to our knowledge of solid state physics.

Group D - Reactive Forces In Fluid Dielectrics

Purpose: Development of high speed electrokinetic propulsive systems for spacecraft. Abstract: Studies of boundary forces (where electrodes are in contact with fluid dielectrics) reveal the existence of a "complex" of inter-acting forces, some of which are purely electrostatic, some electromagnetic and some which could be electrogravitic. The tentative theory requires these electrogravitic forces to be present whenever a mass of dielectric material is charged and moving, and to increase in proportion to the volume of the fluid which is charged and moved. Hence, it is, in a sense, the juxtaposition of the elements of the static form of the capacitor described in Group C experiments, and provides what may be described as an electrokinetic propulsive system, with direct applications to high speed aircraft and spacecraft. Proposal: It is proposed that electrically-charged circular airfoils be mathematically analyzed and improved. Starting with 2 ft. discs at 50 KV, the steps of the development should include 4 ft. discs at 150 KV and a 10 ft. disc at 500 KV. Careful measurements are to be made of both static and dynamic thrust. Studies are also proposed wherein the discs are adapted for vertical lift (levitation) as well as for horizontal thrust and this feature may be incorporated in the design of the 10 ft. experimental model. It is proposed that studies likewise be made of various methods for obtaining the required high voltages, and these studies should include the development and evaluation of the capacitor voltage multiplier and the "flame-jet" electrostatic generator to provide up to 15 million volts (See appendix). This work is to be augmented by the engineering studies on the relative efficiency of propulsion of electrified discs in air at reduced pressure or in vacuum and at various voltages.

Group E - The Spontaneous Generation Of Heat In Certain Complex Silicates, Lavas And Clays.

Purpose: To establish the existence of the positive effects observed by Brush and Harrington, determine the origin of the energy represented and extend the observations into the rare earth /and other/ elements. Abstract: The discovery by Charles Francis Brush of an unexplained heating effect in certain materials is strikingly reminiscent of the discovery of radioactivity by Henri Becquerel which led to the isolation of radium by the Curies. Recent studies have indicated a certain parallelism between the radioactive elements and the rare earth elements, revealing the possibility of a spontaneous release of energy (in this instance in the form of heat alone) by the rare earth elements. Thus, the newly discovered "thermoactivity" may bear the same relationship with the rare earth elements as "radioactivity" bears with the radioactive elements. In all probability the source of the energy represented in thermoactivity will be found in the complex unstable electronic shells of the rare earth atoms, and not in the nuclei as in radioactivity. The anomalous gravitational properties of the rare earth elements and their wide-spread but tenuous occurrence in nature point to other parallels with the radioactive elements such as decay of activity and critical limits of mass. Proposal: 1. Conduct an organized examination of materials (complex silicates, lavas, and clays) known to exhibit spontaneous heating. 2. Conduct a field search for additional materials. 3. Attempt to isolate and purify materials showing spontaneous heating. 4. Extend the examinations into the rare earth metals and tantalum. 5. Conduct mathematical and theoretical studies of gravitational isotopes as distinguished from mass isotopes. 6. Study the mechanism of spontaneous heat generation and the decay of the effect. 7. Study the effects of ionization, electric and magnetic fields upon the effect. 8. Study methods of beneficiation of materials for intensification of the heating effect.

Group F - Navigational And Flight Control Instruments

1. Gravitational Vector (stable vertical) 2. Accelerometer (inertial gradient) 3. Gravitational Gradient (gravity) Purpose: Engineering development and design, adaptation for operation in conjunction with servo mechanisms for actuating flight control devices. Abstract: The physical principles underlying the operation of these instruments have evolved from the findings of C. F. Brush (see appendix - references). Quite recently, careful studies of the records of the Brush experiments have been made. The conclusions, while still highly controversial, leave no doubt that the Brush concept, if supported, can provide answers to many difficult and, as yet unsolved, problems in navigational and flight control instrumentation. The Brush findings may be expressed simply: "the ratio of mass to weight is not the same for

all kinds of matter, as has been supposed, and the mass-weight ratio is not constant even in the same kind of matter". Based on the hypothesis of the non- equivalence of mass and weight, the principles of three instruments have evolved as follows: 1. Gravitational vector (stable vertical) Two equal (inertial) masses of unequal weight are utilized in a balanced pivoted device. Such a device may be said to be inertially symmetrical and gravitationally asymmetrical. The pivoted system will orient itself to the vector of gravity and yet remain insensitive to the inertial effects of acceleration and centrifugal force. 2. Accelerometer (inertial gradient) Two unequal (inertial) masses of equal weight disposed in a pivoted device as above, but with spiral spring (or the like) tending to restore the movable system to zero position. The pivoted element responds quantitatively to inertial effects of acceleration and centrifugal force but is insensitive to gravity. 3. Gravitational Gradient (gravity) Such an instrument is the reverse of the accelerometer above and structurally resembles the gravitational vector indicator except that it includes a spring which is adjusted to restore the indication to zero in the absence of a gravitational field. The movable element responds quantitatively to gravity (g) only and is completely insensitive to all inertial effects such as acceleration or centrifugal force. Proposal: It is proposed that operating models of the three types of instruments be constructed and tested on a centrifugal carriage. Materials for the dipoles of the pivoted systems are to be selected from benificiated gravitational isotopes (both light and heavy) developed under Group E. These prototype instruments are to be adaptable for operation in conjunction with telemetric circuits or servo mechanisms for actuating flight control devices. IMPLEMENTATION (a) Laboraory facilities To be supplied directly by the parent company or its subsidiaries. (b) Personnel Members of the regular research and engineering staff of the parent company and its subsidiaries, with services of such technical or operational consultants as may be necessary. (c) Sub-contracts To be awarded only when it is impractical or uneconomical to perform the work with company facilities. CONDENSED SCHEDULE AND ESTIMATED COST 1955 - October through December (3 months only) Organizational work and planning ($ 3,000.00) Establishment of technical reference library on gravitation and allied subjects ($ 5,000.00) Preliminary beneficiation of gravitational isotopes ($ 12,500.00) Engineering design of flight control instruments ($ 12,500.00) Quantitative tests of Biefeld_Brown effects in solid dielectrics ($ 9,500.00) Basic tests on propagation of gravitational waves for communication purposes ($15,000.00) Total ($ 57,500.00) 1956 - 1958 (3 years) Detailed schedule and expenditures to be determined during the preliminary organizational and planning stage. Respectfully submitted. T. Townsend Brown Consultant Washington D. C. December 1, 1955 Condensed Outlines of Proposed Fundamental Research SECTION A - ANOMALOUS BEHAVIOR OF MASSIVE HIGH-K DIELECTRICS: I - General Description. II - Investigation of the Biefeld-Brown Effect (a) Basic pendulum experiment 1. Effects of mass 2. Effects of K in fluid media 3. High vacuum tests 4. Mathematical relationships involved, derivation of equation (b) Series-capacitor experiments: 1. Effects of mass 2. Effects of K in internal dielectric 3. Effects of K in external fluid dielectric 4. External electrostatic forces 5. Effects of shielding (c) Variations of ponderomotive forces with time: 1. Studies of possible causes 2. Design of continuous recording instrument III - Variations of K with electrostatic potential and/or gravitational potential (a) Studies of hypothesis; mathematical relationships involved. (b) Implications of effect of electrostatic potential and gravitational potential upon: 1. speed of light 2. rates of nuclear fission (c) Measurement of change in potential difference in capacitors with change in electrostatic potential and/or gravitational potential (d) Studies looking toward a possible corresponding change in (w) with electrostatic potential and/or gravitational potential IV - Studies of massive high-K dielectrics (a) Theory of dielectrics, sources of polarization (b) Detailed examination of titanium oxide, barium titanate, lithium thallium tartrate - looking toward increasing values of K (c) Measurement of ponderomotive forces developed by series capacitors containing high-K dielectrics: 1. With applied potential in steady state 2. With changing potential 3. Effects of varying rate-of-change (d) Potential differences developed in polarized materials with change in over-all electrostatic potential 1. Effects of mass 2. Effects of K (e) Stability of electrets: 1. Anomalous rates of voltage decay 2. Diurnal variations V - Analysis of Electrified Disc-airfoils (a) Theoretical considerations (b) Thrust measurements: 1. In air at reduced pressure 2. In hard vacuum 3. In fluid dielectrics of various K 4. Effects of viscosity of fluid dielectrics SECTION B - ELECTROGRAVITIC INDUCTIVE EFFECTS: I - General Description II - Investigation of the Fernando Sanford Effect (a) Repeat experiments (b) Series-capacitor experiments (c) Theoretical considerations III - Studies of Potential Variations (a) In large insulated masses (b) Effects of mass (c) In capacitors (d) Electrical potential vs. gravitational potential (e) The mountain effect (f) Centrifugal potential effects IV - Studies of Voltage Gradients in Dielectric Materials (a) Long-series capacitors (b) Effects of mass (c) Directional gravitational effects V - Polar Capacitors (a) Shift of potential of the mid-point (b) Directional effects (c) Effects of elevation from earth (d) Tests below earth surface VI - Short-period Gravity Meter (a) Design and Construction (b) Detection of gravitational waves REFERENCE: Terrestrial Electricity, Fernando Sanford, Professor Emeritus of Physics - Stanford University. Stanford University Press. SECTION C - DETERMINATIONS OF TIDAL EFFECTS ON BROWN DIFFERENTIAL ELECTROMETER I - General Description II - Analysis of Zanesville and Philadelphia observations (a) Solar component (b) Sidereal component (c) Lunar components, correlations with: 1. Lunar hour angle 2. Angular distance, phase 3. Distance from earth 4. Altitude of moon 5. Right ascension of moon (d) Studies of combined effects (e) Detailed comparison of Zanesville and Philadelphia observations (f) Comparison with simple tidal curves: 1. Ocean tides 2. Atmospheric tides, barometric (Maris effect) (g) Secular changes (h) Correlation with other natural variables III - Analysis of California observations (a) Secular changes (b) Solar, lunar and Sidereal components (c) 75th meridian and 120th meridian observations (d) Regional vs world-wide variations (e) Local variations (f) Correlation with other factors IV - Analysis of Fernando Sanford Records (a) Solar, lunar and sidereal components (b) Comparison with Zanesville and Philadelphia records (c) Comparison with atmospheric electric gradient and earth current records V - Analysis of Section A electrometer observations (Current Program) (a) Studies related to gravitational and electrical variables (b) Secular changes (c) Comparison with former records VI - Analysis of Section D thermoactivity observations (Current Program) (a) Diurnal variations (b) Secular changes (c) Comparison with Section V records SECTION D - GRAVITATIONAL ISOTOPES I - Investigation of the Charles Francis Brush Effects (a) Impairment of gravitational acceleration: 1. In complex silicates, lavas and clays 2. In barium aluminate, barium titanate and other high-K materials (b) Persistent generation of heat: 1. Calorimetric analysis 2. Mass effect, particle size 3. Diurnal variations (c) Correlations between (a) and (b) II - Studies of Gravitational Isotopes as Distinguished from Mass Isotopes (a) Definitions (b) Theoretical considerations (c) Gravitational periodic table of the elements: 1. Specific gravities with positive and negative anomalies 2. The Lanthanide contraction 3. Parallels between the lanthanide and actinide series of elements (d) Spontaneous evolution of heat: 1. Parallels between thermoactivity and radioactivity 2. Decay of thermoactivity, increase of gravitational mass, computations of half-life 3. Exponential increase in thermoactivity with total (localized) mass 4. Possibilities of "critical mass" effects (e) Determination of origin of energy: 1. Unstable electron shells 2. Dirac "holes" 3. Possibilities of negative mass. Lofting properties 4. Effects of electric and magnetic fields 5. Effects of changes in electric and/or gravitational potential 6. Diurnal and secular variations in thermoactivity and/or weight III - Beneficiation of Gravitational Isotopes (a) Occurrence in nature: 1. In all elements 2. In rare-earth elements 3. In special cases (b) Nascent gravitational isotopes: 1. Enrichment following chemical or nuclear reactions 2. Presence in reaction products of nuclear reactors 3. Breeder technique (c) Methods of beneficiation: 1. Settling and centrifuging 2. Settling and thermal diffusion IV - Possible Uses of Gravitational Isotopes (a) Super-light (and super-heavy) fractions for: 1. Materials of construction (alloys) 2. Sensitive elements of navigational instruments (b) Contra-terrene (negative gravitational mass) possibilities as (fixed lift) lofting agents: 1. Materials of construction for aircraft and spacecraft 2. Lofting "capsules" (c) As a source of heat 1. Building materials (and the like) where slight warming effect is desired 2. Steam generation (similar to but less energetic than nuclear fuels) 3. Explosives

REFERENCES: Brush, C.F., Physical Review, 31, p 1113(A), 32, p 633 abstract; Proc. Amer. Philosophical Soc. Vol.IX No. 2, 1921; Vol. LXVII No. 2, 1928; Vol LXVIII No. 1, 1929; Journal of Franklin Inst., Vol. 206, No. 1, 1928. Harrington, E.A., Nat'l Bu. of Standards, Proc. Amer. Philosophical Soc., Vol. LXXII, No. 5, 1933.

Gravitational Periodic Table Of The Elements indicating parallel relationships 1 Hydrogen GROUP I GROUP II 2 Helium . . . . .10 Neon 3 Lithium . . . . .11 Sodium 4 Beryllium . . . . .12 Magnesium 5 Boron . . . . .13 Aluminum 6 Carbon . . . . .14 Silicon 7 Nitrogen . . . . .15 Phosphorus 8 Oxygen . . . . .16 Sulfur 9 Flourine . . . . .17 Chlorine GROUP III GROUP IV 18 Argon . . . . 36 Krypton 19 Potassium. . . . . 37 Rubidium 20 Calcium . . . . 38 Strontium 21 Scandium . . . . 39 Yttrium 22 Titanium . . . . 40 Zirconium 23 Vanadium . . . . 41 Niobium 24 Chromium . . . . 42 Molybdenum 25 Manganese. . . . . 43 Technicium 26 Iron . . . .

. . 44 Ruthenium 27 Cobalt . . . . 45 Rodium 28 Nickel . . . . 46 Palladium 29 Copper . . . . 47 Silver 30 Zinc . . . . 48 Cadmium 31 Gallium . . . . 49 Indium 32 Germanium. . . . . 50 Tin 33 Arsenic . . . . 51 Antimony 34 Selenium . . . . 52 Tellurium 35 Bromine . . . . 53 Iodine GROUP V GROUP VI 54 Zenon . . . . 86 Radon 55 Caesium . . . . 87 Francium 56 Barium . . . . 88 Radium 57 Lanthanum . . . . 89 Actinium 58 Cerium . . . . 90 Thorium 59 Praseodymium. . . . . 91 Proactinium 60 Neodymium . . . . 92 Uranium 61 Promethium . . . . 93 Neptunium 62 Samarium . . . . 94 Plutonium 63 Europium . . . . 95 Americium 64 Gadolinium . . . . 96 Curium 65 Terbium . . . . 97 Berkelium 66 Dysprosium . . . . 98 Californium 67 Holmium . . . . 99 Einsteinium 68 Erbium . . . . 100 Fermium 69 Thulium . . . . 101 70 Ytterbium . . . . 102 71 Lutecium . . . . 103 72 Halfnium . . . . 104 73 Tantalum . . . . 105 74 Tungsten . . . . 106 75 Rhenium . . . . 107 76 Osmium . . . . 108 Newtonium 77 Iridium . . . . 109 78 Platinum . . . . 110 79 Gold . . . . 111 80 Mercury . . . . 112 81 Thallium . . . . 113 82 Lead . . . . 114 83 Bismuth . . . . 115 84 Polonium . . . . 116 85 Astatine . . . . 117 Research and Prelim. Engineering Space Vehicle Program General Objectives: In the following outlines of fundamental research, specific details have been referred to for the purpose of imparting a clear understanding of the nature of the proposed investigations. These preliminary outlines should not be construed as limiting the scope or delineating special interest. The goal of the project is a carefully integrated and adequately financed study of gravitation, embracing every relationship between gravitation and electrodynamics. It is to be remarked that the problem of relating gravitation to electrodynamics and the quantum theory is one which has taxed the ingenuity of some of the best mathematical brains for the last 30 years. So for, no very complete or satisfactory resolution of the matter has been found. Yet we are not completely in the dark with regard to it and the situation today is far from discouraging. The so-called "red-shift" produced by gravitation, and even the deviation of light by stars, are phenomena which are concerned with a relationship between gravitation and electrodynamics. Even though they are cosmological in extent, the magnitudes of these phenomena are small. Effects recently discovered in massive dielectrics point to the existence of hitherto unsuspected gravitational relationships and appear to have brought the matter for the first time into the realm of terrestrial experimentation. No one can deny the possibility that, as a result of this and other discoveries, a concept may result which so revolutionizes all our previous thoughts on gravity, electrodynamics and quantum theory as to render the story of the inter-relations of these fields one of consistency and satisfaction. No one can deny that such inter-relationships would have very profound significance. Such a program as herein outlined is necessarily of long-range. Unquestionably, there will be found many productive avenues of exploration which cannot be described in detail or even foreseen at the present time. Policy: The project must adopt a policy of inviting assistance from able physicists interested in the special problems involved. It must not fail to take into account and investigate any phenomena which bears even remotely upon the subject. For example, in the study of physical properties of dielectrics, low-temperature research may be highly fruitful. Electrodynamic phenomena occur at low- temperatures which are completely unknown at room temperature. The possibilities of discovering wholly unsuspected gravitational effects below the superconductivity threshold, at temperatures approaching absolute zero, appear to be worth the costs involved. Library: The establishment of an adequate reference library on gravitation and related subjects, for the accumulation of technical information and to serve as liaison with academic institutions throughout the world, is a requirement of utmost importance particularly at the beginning of the program. Highest Priority: No one can guarantee results in research. No one can predict the direction the research will take. It is the express purpose of this project to obtain the technical answers as rapidly as possible by forming a coordinated program in which the best minds and all necessary laboratory facilities are brought together. It is the sincere hope that, in this way, a century of normal evolution in science, especially toward a better understanding of the nature of gravitation, may be compressed into from 5 to 10 years. Such a program is expensive but, as it was with the atomic bomb project in America, money was traded to gain a far more valuable commodity - time. So it may also be with man's ultimate conquest of space. As a necessary and inevitable prerequisite, a concerted study of gravitation is clearly indicated. We are forced to the conclusion that a research program organized specifically for this purpose can no longer be neglected. The Trouton-Noble Experiment (with massive dielectrics): The experiment concerns itself with an electromagnetic torque operating on a charged condenser which moves with uniform velocity in a direction inclined to the normal of its surface. According to the theory of relativity, compensating effects, in this case having to do with the effect of the dielectric materials in the condenser on the torque aforesaid. In the days before universal acceptance of the theory of relativity, there was a reason to believe that measurements of the rotation of such a condenser as the above, when supported by some suspension, would serve to determine the velocity of the earth's motion through space. If, for a moment, we put ourselves in the mind of one who does not accept the theory of relativity in its entirety or wishes to test its validity further, the torque described above and possible rotation resulting from it becomes matters of experimental interest. A situation of great interest centers around the effect of the dielectric materials in the condenser on the torque. Now it appears that the original calculation of the torque is completely erroneous; and it appears that if the torque had been calculated correctly, invoking the same fundamental principles as were invoked in the earlier calculations, it would have been found to depend only upon the potential difference between the plates of the condenser and to be independent of the dielectric constant. However, a more refined analysis of the situation, which does not simply average the properties of the polarized molecules into a representation in terms of a dielectric constant, reveals that there may be a contribution to the torque which depends on the nature of the molecular dipoles, and in a manner which is not expressible in terms of the dielectric constant. The above conclusions were reached by Kennard and Swann independently by different processes of mathematical analysis. They have rendered the Trouton-Noble experiment one of considerable interest to a person who had any doubts about the theory of relativity, and the interest would be enhanced by the bearing of the nature of the dielectric material upon the outcome of the experiment. Mass of the Electrons in Metals: This experiment has to do with the observations of momentum in a ring of conducting material carrying a current at the instant when the material is carried from the super-conducting to the non-superconducting state. Briefly, the above experiment envisages a metal ring in which a current of electricity has been produced by the creation of a magnetic field passing through the ring when all is at a temperature such that the super-conducting state prevails. Under such conditions, the current will continue practically indefinitely. If we now raise the temperature, the super-conductivity will disappear at a certain critical temperature, and the annular momentum of the electric current will be shared with the ordinary material of the ring in such a way as to give an angular rotation to the latter. The ring is, of course, to be envisaged as supported by a suspension and the angular rotation observed will depend upon the stiffness of this suspension. An interesting feature of the experiment lies in the fact that the sensitivity is greatest when the cross-section of the wire of the ring is smallest. The limiting conditions which determine the ultimate sensitivity are based upon the requirement that when the energy of the current is dissipated and the metal of the ring passes through the super-conducting state, the heat evolved shall not be sufficient to burn up the apparatus. The fundamental theoretical interest of the experiment lies in the fact that the angular rotation obtained depends upon the electronic mass, and theoretical considerations have been presented to support the belief that this electronic mass may be different for the electrons in a metal than for the electrons in a free state. Most authorities on quantum theory are of the opinion that the effective mass of the electron in a metal is the same as that for an electron in a free state. However, even those who support this view are in favor of performing the experiment because of the complexity of the theoretical considerations involved. The most fundamental requirement is, of course, a means of producing liquid helium, and this implies a cryostat. If a cryostat were obtained, the potentialities of an enormous amount of other work in solid state physics would be provided for. Investigation of High-K Dielectrics at Low Temperatures: Research in solid state phenomena with special relation to dielectrics of high-K is of great current interest. Investigation of the properties of substances of high-K should be made in the realms of breakdown resistance, ferro-electrets, hysteresis, and allied phenomena. Special interest attaches also to the characteristics of electrets as such and to the conditions necessary to secure high activity of such electrets over long periods of time. In all the foregoing work, low temperature researches involving the cryostat would be of fundamental importance; for although the dielectrics are not usually used at low temperatures, many of the characteristics which determine their behavior at ordinary temperatures can be examined more readily by experiments performed at low temperatures. A survey of the literature on low temperature phenomena shows a large amount of work which has been carried out on the properties of paramagnetic salts, whereas the properties of dielectric materials have hardly been investigated at all. The reasons for this difference in emphasis are essentially understood. At liquid helium temperatures, the system of magnetic moments in most of the common paramagnetic salts is still in a thermally disordered state so that its magnetic properties are still varying with temperature in an interesting fashion. In addition, since the technique of adiabatic demagnetization of a paramagnetic salt is the sole means, at the present time, of producing temperatures well below 1oK, it is only natural that a great amount of effort has been spent in the elucidation of the properties of these materials. Most normal dielectric materials show a negligible variation of their dielectric properties with temperature, especially in the liquid helium region. This may be seen by looking at the main sources of polarization in a dielectric, namely: 1. The electric polarizability, which arises from the fact that the outer electrons of an atom can be displaced with respect to the nucleus by an external electric filed thereby creating a dipole moment. This is a property of the particular atom under consideration and is independent of temperature. 2. The ionic polarizability, arising from the displacement of positive ions with respect to negative ions in an ionic crystal. In most materials, this type of polarizability varies only very slowly with temperature, leading to a slight variation of dielectric constant with temperature. That this is not always the case is the reason for the present proposal. 3. Polarization due to the alignment of molecules with permanent dipole moments. In solids where the molecule is not free to rotate, this effect is absent. In recent years, a number of ferroelectric compounds have been discovered which are practically completely analogous in their dielectric behavior to ferromagnetic materials. Thus they show a Curie temperature, above which the dielectric constant follows a Curie-Weiss law and below which they exhibit spontaneous electrical polarization and hysteresis properties. Barium titanate (BaTiO3) is the best known of these compounds. Most of these compounds have Curies temperatures which are fairly high. Two compounds are known which have very low Curie temperatures. These are Potassium Tartrate (KTiO3) and Lithium Thallium Tartrate (LiTiC4H4O6.H2O), with Curie temperatures at 13.2oK and 10oK respectively. The existence of these very low Curie temperatures has created an additional interest in the study of dielectrics at the low temperatures obtainable with a Collins Helium cryostat. In addition to the intrinsic value of a program on the properties of dielectrics at low temperatures, it is conceivable that it might be possible to provide another means of producing temperatures lower than 1oK other than adiabatic demagnetization. If one had a ferroelectricmaterial with a Curie temperature well below 1oK, then by the adiabatic, reversible depolarization of the material, it should be possible to produce a cooling effect (electro-caloric effect). since the equipment involved in this process is somewhat simpler than in the corresponding magnetic case, it would be of considerable interest to investigate its feasibility. This method is not applicable below the Curie temperature since the presence of hysteresis and spontaneous polarization introduces irreversible heating effects upon applying or removing an external electric field. The Curie temperature of BaTiO3 can be decreased by reducing the lattice parameter either by the addition of strontium or by application of external pressure. Presumably, this technique can be used to decrease the Curie temperature of KTiO3 or LiTiC4H4O6.H2O. An understanding of the factors which influence the Curie temperature and of the range of Curie temperatures in different crystals is important for the development of a basic theory of ferroelectricity. In summary, it appears that a program on the properties of dielectrics at low temperatures can contribute substantially to an understanding of solids. The starting point for this program should logically be an investigation of KTiO3 and LiTiC4H4O6.H2O as well as structurally similar crystals and their solid solutions with each other. Electromagnetic Equations for the Super-Conductive State: Among the many interesting phenomena which occur at low temperatures, superconductivity has long held the attention of experimentalist and theoretician alike since its discovery by H. Kammerlingh Onnes in 1911. With the discovery of the Meissner effect in 1933, the basic experimental behavior necessary for the development of an electrodynamic theory of super-conductivity has been established. F. and H. London, in 1935, developed a set of equations which describe the macroscopic electrodynamic behavior of super-conductors in a quantitative manner to the present time. One experiment which would shed considerable light on the correctness of these equations has been suggested by F. London. This experiment involves a study of the magnetic properties of a rotating sphere. The theory of this experiment is worked out in complete detail by F. London. The following is a physical description of the nature of this experiment. Consider a sphere of radius R. If we start with the sphere at rest below its super-conducting transition temperature and bring it into motion with uniform angular velocity (w), then by considering the super-conducting electrons are perfectly free it can be deduced that the sphere should become magnetized upon rotation. The reason for this is as follows: When the sphere is initially set into motion, the electrons - being perfectly free from interaction with the crystal lattice - will not move with the sphere, and a current is set up due to their relative motion. This changing current in turn induces an electric field within the sphere which acts on the electrons in such a manner as to accelerate them in the direction of rotation of the sphere. The final result is that when the sphere has reached a constant angular velocity the super-conducting electrons everywhere move with the sphere except for a narrow layer at the surface, where they lag behind slightly to produce a small current. This result was predicted on the basis of a free electron theory before the development of the theory of F. and H. London. The London theory predicts the same result for the rotating sphere, except that it makes and additional prediction. F. London states that the rotating sphere will have a magnetic moment independent of the prehistory the sphere. In particular, if a rotating sphere is cooled below its transition temperature while rotating, the sphere will acquire the same magnetic moment as it would upon starting from rest below its transition temperature and being brought to the same angular velocity. On the basis of a free electron theory of super-conductivity, it is difficult to understand how a sphere which is already rotating will suddenly acquire a magnetic moment upon being cooled below its transition temperature. In this case, the electrons move with the sphere above the transition temperature due to their finite interaction with the lattice (finite resistance). That they should suddenly lag behind to produce a magnetic moment on cooling below the transition temperature seems surprising. The magnetic moment predicted for the rotating sphere is small, but should be measurable with sufficiently careful experimental technique. This experiment would constitute a fundamental method of testing the basic assumptions of the London theory.