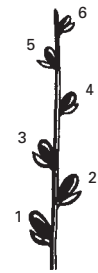
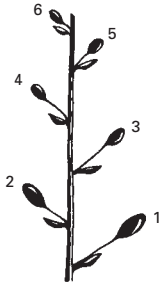
R

Rabi model A quantum mechanical model describing the interaction between a two-level system and an electromagnetic field. The model was originally proposed by the Galician-born American physicist Isidor Rabi (1898–1988) in the context of *nuclear magnetic resonance, with the two levels being spin-up and spin-down and the field being an external magnetic field.

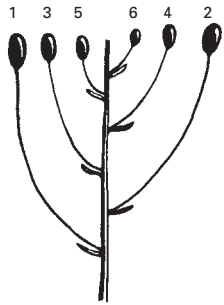
race 1. (in biology) A category used in the *classification of organisms that consists of a group of individuals within a species that are geographically, ecologically, physiologically, or chromosomally distinct from other members of the species. The term is frequently used in the same sense as *subspecies. **Physiological races**, for example, are identical in appearance but differ in function. They include strains of fungi adapted to infect different varieties of the same crop species.



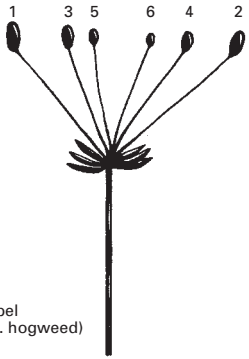
spike
(e.g. plantain)



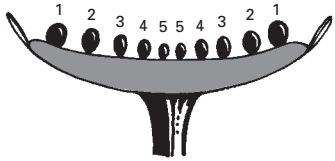
raceme
(e.g. lupin)



corymb
(e.g. candytuft)



umbel
(e.g. hogweed)



capitulum
(e.g. daisy)

1 = oldest flower

Racemose inflorescences.

2. (in anthropology) A distinct human type possessing several characteristics that are genetically inherited. The major races are Mongolian, Caucasian, and Ethiopian.

racemate *See* RACEMIC MIXTURE.

raceme A type of *racemose inflorescence in which the main flower stalk is elongated and bears stalked flowers. An example is the lupin. *See also* PANICLE.

racemic mixture (racemate) A mixture of equal quantities of the (+)- or *d*- and (–)- or *l*- forms of an optically active compound. Racemic mixtures are denoted by the prefix (±)- or *dl*-. A racemic mixture shows no *optical activity.

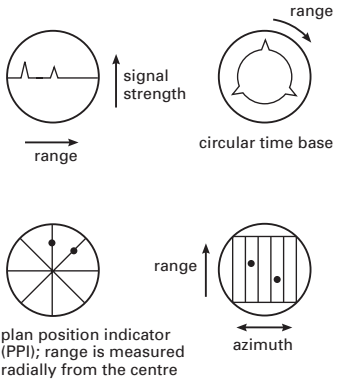
racemization A chemical reaction in which an optically active compound is converted into a *racemic mixture.

racemose inflorescence (indefinite inflorescence) A type of flowering shoot (*see* INFLORESCENCE) in which the growing region at the tip of the flower stalk continues to produce new flower buds during growth. As a result, the youngest flowers are at the top and the oldest flowers are at the base of the stalk. In a flattened inflorescence, the youngest flowers are in the centre and the oldest flowers are on the outside. Types of racemose inflorescence include the *capitulum, *catkin, *corymb, *raceme, *spadix, *spike, and *umbel (see illustration). *Compare* CYMOSE INFLORESCENCE.

rachis (rhachis) **1.** The main axis of a compound leaf or an inflorescence. **2.** The shaft of a *feather. **3.** The backbone.

rad *See* RADIATION UNITS.

radar (radio detection and ranging) A method of detecting the presence, position, and direction of motion of distant objects (such as ships and aircraft) by means of their ability to reflect a beam of electromagnetic radiation of centimetric wavelengths. It is also used for navigation and guidance. It consists of a transmitter producing radio-frequency radiation, often pulsed, which is fed to a movable aerial from which it is transmitted as a beam. If the beam is interrupted by a solid object, a part of the energy of the radiation is reflected back to the aerial. Signals received by the aerial are passed to the receiver, where they are amplified and detected. An echo from a reflection of a solid object is indicated by a sudden rise in the detector output. The time taken for a pulse to reach the object and be reflected back (t) enables the distance away (d) of the target to be calculated from the equation $d = ct/2$, where c is the speed of light. In some systems the speed of the object can be measured using the *Doppler effect. The output of the detector is usually displayed on a cathode-ray tube in a variety of different formats (see illustration).



Radar. Types of cathode-ray tube radar display.

radial symmetry The arrangement of parts in an organ or organism such that cutting through the centre of the structure in any direction produces two halves that are mirror images of each other. The stems and roots of plants usually show radial symmetry, while all animals belonging to the Cnidaria (e.g. jellyfish) and Echinodermata (e.g. starfish) are radially symmetrical – and typically sessile – in their adult form. The term **actinomorphy** is used to describe radial symmetry in flowers (e.g. a buttercup flower). *Compare* BILATERAL SYMMETRY.

radial velocity *See* LINE-OF-SIGHT VELOCITY.

radian *See* CIRCULAR MEASURE.

radiance Symbol L_e. The radiant intensity per unit transverse area, in a given direction, of a source of radiation. It is measured in W sr^{-1} m^{-2}.

radiant energy Energy transmitted as electromagnetic radiation.

radiant exitance *See* EXITANCE.

radiant flux Symbol Φ_e. The total power emitted, received, or passing in the form of

electromagnetic radiation. It is measured in watts.

radiant intensity Symbol I_e. The *radiant flux per unit solid angle emitted by a point source. It is measured in watts per steradian.

radiation **1.** Energy travelling in the form of electromagnetic waves or photons. **2.** A stream of particles, especially alpha- or beta-particles from a radioactive source or neutrons from a nuclear reactor. **3.** *See* ADAPTIVE RADIATION.

radiation belts *See* VAN ALLEN BELTS.

radiation damage Harmful changes that occur to inanimate materials and living organisms as a result of exposure to energetic electrons, nucleons, fission fragments, or high-energy electromagnetic radiation. In inanimate materials the damage may be caused by electronic excitation, ionization, transmutation, or displacement of atoms. In organisms, these mechanisms can cause changes to cells that alter their genetic structure, interfere with their division, or kill them. In humans, these changes can lead to **radiation sickness**, **radiation burns** (from large doses of radiation), or to long-term damage of several kinds, the most serious of which result in various forms of cancer (especially leukaemia).

radiationless decay Decay of an atom or molecule from an excited state to a lower energy state without the emission of electromagnetic radiation. A common example of a radiationless process is the *Auger effect, in which an electron rather than a photon is emitted as a result of decay.

radiation pressure The pressure exerted on a surface by electromagnetic radiation. As radiation carries momentum as well as energy it exerts a force when it meets a surface, i.e. the *photons transfer momentum when they strike the surface. The pressure is usually negligible on large bodies, for example, the pressure of radiation from the sun on the surface of the earth is of the order of 10^{-5} pascal, but on small bodies it can have a considerable effect, driving them away from the radiation source. Radiation pressure is also important in the interiors of stars of very high mass.

radiation temperature The surface temperature of a celestial body as calculated by *Stefan's law, assuming that the body behaves as a *black body. The radiation temperature is usually measured over a narrow portion of the electromagnetic spectrum, such as the visible range (which gives the **optical temperature**).

radiation units Units of measurement used to express the *activity of a radionuclide and the *dose of ionizing radiation. The units **curie**, **roentgen**, **rad**, and **rem** are not coherent with SI units but their temporary use with SI units has been approved while the derived SI units **becquerel**, **gray**, and **sievert** become familiar.

The becquerel (Bq), the SI unit of activity, is the activity of a radionuclide decaying at a rate, on average, of one spontaneous nuclear transition per second. Thus 1 Bq = 1 s^{-1}. The former unit, the curie (Ci), is equal to 3.7×10^{10} Bq. The curie was originally chosen to approximate the activity of 1 gram of radium–226.

The gray (Gy), the SI unit of absorbed dose, is the absorbed dose when the energy per unit mass imparted to matter by ionizing radiation is 1 joule per kilogram. The former unit, the rad (rd), is equal to 10^{-2} Gy.

The sievert (Sv), the SI unit of dose equivalent, is the dose equivalent when the absorbed dose of ionizing radiation multiplied by the stipulated dimensionless factors is 1 J kg^{-1}. As different types of radiation cause different effects in biological tissue a weighted absorbed dose, called the **dose equivalent**, is used in which the absorbed dose is modified by multiplying it by dimensionless factors stipulated by the International Commission on Radiological Protection. The former unit of dose equivalent, the rem (originally an acronym for *r*oentgen *e*quivalent *m*an), is equal to 10^{-2} Sv.

In SI units, exposure to ionizing radiation is expressed in coulombs per kilogram, the quantity of X- or gamma-radiation that produces ion pairs carrying 1 coulomb of charge in 1 kilogram of pure dry air. The former unit, the roentgen (R), is equal to 2.58×10^{-4} C kg^{-1}.

radiative collision A collision between charged particles in which part of the kinetic energy is radiated in the form of photons.

radiative forcing Any perturbation in the balance of incoming and outgoing radiation (i.e. the net irradiance) at the upper surface of the earth's atmosphere, the troposphere. Such a perturbation forces a change in the earth's climate system until a new irradiance

balance is attained. Positive radiative forcing has a warming effect, whereas negative radiative forcing causes the system to cool. Various factors, both natural and anthropogenic (human-derived), can lead to radiative forcing, notably changes in incoming solar radiation or atmospheric reflectivity (albedo). For example, the albedo is increased by a rise in concentration of tropospheric sulphate aerosols derived from volcanic eruptions, producing a cooling effect. Conversely, greenhouse gases, such as carbon dioxide and methane, absorb outgoing infrared radiation, causing positive forcing and hence warming.

radical **1.** (in chemistry) A group of atoms, either in a compound or existing alone. *See* FREE RADICAL; FUNCTIONAL GROUP. **2.** (in mathematics) A root of a number or a quantity. The symbol $\sqrt{}$ is called the **radical sign**.

SEE WEB LINKS

- Information about IUPAC nomenclature
- List of radical names

radicle The part of a plant embryo that develops into the root system. The tip of the radicle is protected by a root cap and points towards the micropyle. On germination it breaks through the testa and grows down into the soil. *Compare* PLUMULE.

radio A means of transmitting information in which the transmission medium consists of electromagnetic radiation. Information is transmitted by means of the *modulation of a *carrier wave in a transmitter; the modulated carrier wave is fed to a transmitting aerial from which it is broadcast through the atmosphere or through space. A receiving aerial forms part of a *resonant circuit, which can be tuned to the frequency of the carrier wave, enabling the receiver that it feeds selectively to amplify and then to demodulate the transmitted signal. A replica of the original information is thus produced by the receiver. *See also* RADIO TRANSMISSION.

radioactive age The age of an archaeological or geological specimen as determined by a process that depends on a radioactive decay. *See* CARBON DATING; FISSION-TRACK DATING; POTASSIUM–ARGON DATING; RUBIDIUM–STRONTIUM DATING; URANIUM–LEAD DATING.

radioactive dating The determination of the age of a geological or archaeological specimen by a process that depends on radioactive decay. The age so determined is known as the **radioactive age**. *See* CARBON DATING; FISSION-TRACK DATING; POTASSIUM–ARGON DATING; RUBIDIUM–STRONTIUM DATING; URANIUM–LEAD DATING.

radioactive series A series of radioactive nuclides in which each member of the series is formed by the decay of the nuclide before it. The series ends with a stable nuclide. Three radioactive series occur naturally, those headed by thorium–232 (**thorium series**), uranium–235 (**actinium series**), and uranium–238 (**uranium series**). All three series end with an isotope of lead. The neptunium series starts with the artificial isotope plutonium–241, which decays to neptunium–237, and ends with bismuth–209.

radioactive tracing *See* LABELLING.

radioactive waste (nuclear waste) Any solid, liquid, or gaseous waste material that contains *radionuclides. These wastes are produced in the mining and processing of radioactive ores, the normal running of nuclear power stations and other reactors, the manufacture of nuclear weapons, and in hospitals and research laboratories. Because high-level radioactive wastes can be extremely dangerous to all living matter and because they may contain radionuclides having half-lives of many thousands of years, their disposal has to be controlled with great stringency. High-level waste (e.g. spent nuclear fuel) requires to be cooled artificially and is therefore stored for several decades by its producers before it can be disposed of. Intermediate-level waste (e.g. processing plant sludge and reactor components) is solidified, mixed with concrete, packed in steel drums, and stored in special sites at power stations before being buried in concrete chambers in deep mines or below the seabed. Low-level waste (e.g. solids or liquids lightly contaminated by radioactive substances) is disposed of in steel drums in special sites in concrete-lined trenches.

radioactivity The spontaneous disintegration of certain atomic nuclei accompanied by the emission of alpha particles (helium nuclei), beta particles (electrons or positrons), or gamma radiation (short-wavelength electromagnetic waves).

Natural radioactivity is the result of the spontaneous disintegration of naturally occurring radioisotopes. Many radioisotopes can be arranged in three *radioactive series. The rate of disintegration is uninfluenced by chemical changes or any normal changes in

their environment. However, radioactivity can be induced in many nuclides by bombarding them with neutrons or other particles. *See also* DECAY; IONIZING RADIATION; RADIATION UNITS.

radio astronomy The study of the radio-frequency radiation emitted by celestial objects, from planets and stars to nebulae, galaxies, and quasars. This branch of astronomy began in 1932 when a US engineer, Karl Jansky (1905–40), first detected radio waves from outside the earth's atmosphere by pointing a radio antenna at the centre of the Galaxy in Sagittarius. *See* RADIO SOURCE; RADIO TELESCOPE; RADIO WINDOW.

radiobiology The branch of biology concerned with the effects of radioactive substances on living organisms and the use of radioactive tracers to study metabolic processes (*see* LABELLING).

radiocarbon dating *See* CARBON DATING.

radiochemistry The branch of chemistry concerned with radioactive compounds and with ionization. It includes the study of compounds of radioactive elements and the preparation and use of compounds containing radioactive atoms. *See* LABELLING; RADIOLYSIS.

radio frequencies The range of frequencies, between about 3 kilohertz and 300 gigahertz, over which electromagnetic radiation is used in radio transmission. It is subdivided into eight equal bands: *very low frequency, *low frequency, *medium frequency, *high frequency, *very high frequency, *ultra high frequency, *super high frequency, and *extremely high frequency.

radio galaxies A *radio source outside the Galaxy that has been identified with an optically visible galaxy. These radio galaxies are distinguished from normal galaxies by having a radio power output some 10^6 times greater (i.e. up to 10^{38} watts rather than 10^{32} W). The source of the radio-frequency energy is associated with violent activity, involving the ejection of relativistic jets of particles from the nucleus of the galaxy. It has been suggested that the radio sources are powered by supermassive *black holes in the nucleus.

radiogenic Resulting from radioactive decay.

radiography The process or technique of producing images of an opaque object on photographic film or on a fluorescent screen by means of radiation (either particles or electromagnetic waves of short wavelength, such as X-rays and gamma-rays). The photograph produced is called a **radiograph**. The process is widely used in diagnostic *radiology, using X-rays, and in flaw detection in industrial products, using high-energy X-rays, gamma-radiation, neutron beams, and (more recently) beams of charged particles. *See also* AUTORADIOGRAPHY.

radio interferometry *See* RADIO TELESCOPE.

radioisotope (radioactive isotope) An isotope of an element that is radioactive. *See* LABELLING.

radiolocation The location of distant objects by means of *radar.

radiology The study and use of X-rays, radioactive materials, and other ionizing radiations for medical purposes, especially for diagnosis (**diagnostic radiology**) and the treatment of cancer and allied diseases (**therapeutic radiology** or **radiotherapy**).

radiolysis The use of ionizing radiation to produce chemical reactions. The radiation used includes alpha particles, electrons, neutrons, X-rays, and gamma rays from radioactive materials or from accelerators. Energy transfer produces ions and excited species, which undergo further reaction. A particular feature of radiolysis is the formation of short-lived solvated electrons in water and other polar solvents.

radiometric dating (radioactive dating) *See* DATING TECHNIQUES; RADIOACTIVE AGE.

radionuclide (radioactive nuclide) A *nuclide that is radioactive.

radiopaque (radio-opaque) Describing a medium that is opaque to X-rays and gamma rays. Examples are barium salts, used in diagnostic radiology of the digestive tract. *See also* OPACITY.

radiopharmaceuticals Compounds used in medicine that have a radioactive atom in the molecule. Radiopharmaceuticals are used both for diagnostic purposes (as in radionuclide imaging) or for therapy (e.g. certain cancer treatments).

radiosonde A meteorological instrument that measures temperature, pressure, humidity, and winds in the upper atmosphere. It consists of a package of instruments and a

radio transmitter attached to a balloon. The data is relayed back to earth by the transmitter. The position of the balloon can be found by radar and from its changes in position the wind velocities can be calculated.

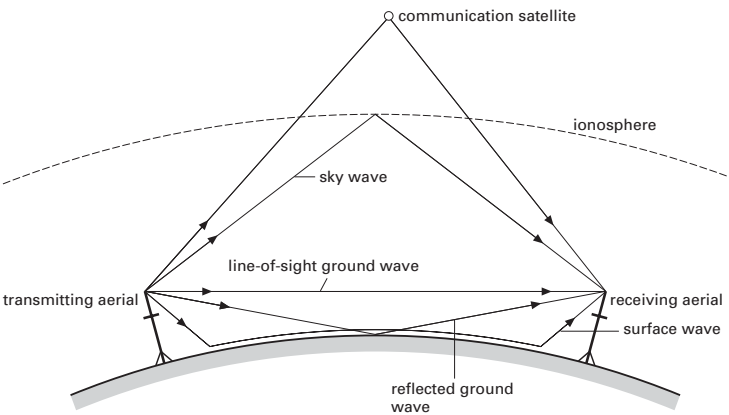
radio source An astronomical object that has been observed with a *radio telescope to emit radio-frequency electromagnetic radiation. Radio sources within the Galaxy include Jupiter, the sun, pulsars, star-forming regions, supernova remnants, and background radiation arising from *synchrotron radiation. Sources outside the Galaxy include galaxies, *radio galaxies, and *quasars. Radio sources were formerly known as **radio stars**.

radio star *See* RADIO SOURCE.

radio telescope An instrument for detecting and measuring electromagnetic radiation of radio frequencies that have passed through the *radio window in the earth's atmosphere and reached the surface of the earth. There are a great diversity of *radio sources within the universe and radio telescopes are required to detect both continuous emissions and specific spectral lines. They therefore require the highest possible angular resolution so that the details of radio sources can be studied and they should be able to pick up weak signals. The simplest radio telescope consists of a paraboloidal steerable-dish aerial together with ancillary amplifiers. The paraboloidal dish surface reflects the incoming signal to the principal focus of the reflector. At this point the radio-frequency signals are amplified up to 1000 times and converted to a lower, intermediate, frequency before transmission by cable to the control building. Here the intermediate frequency is amplified again and passed to the detector and display unit. As the radio waves arriving from the surface of the reflector at the focus must be in phase, the surface of the dish must be very accurately constructed; for example, a 100-metre-diameter dish must be accurate to the nearest millimetre, when receiving radiation of 1 cm wavelength. To overcome the problem of constructing large dishes to such a high accuracy, the technique of **radio interferometry** has been developed. In this technique an array of small aerials connected by cable is used to simulate a large dish aerial. In earth-rotation **aperture synthesis**, the individual positions and displacements of an array of only a few such small aerials can be made to simulate an enormous dish aerial as the earth rotates. All but the smallest steerable dishes are constructed from metal mesh so that wind can pass through them. A few very large fixed dishes have been built into the earth's surface.

radiotherapy *See* RADIOLOGY.

radio transmission The transmission of radio waves from a transmitting aerial to a receiving aerial. The radiation may take several paths (see illustration). The sum of the line-of-sight ground wave, the reflected ground wave, and the surface wave is called



Radio transmission.

the **ground wave** (or **tropospheric wave**). **Sky waves** (or **ionospheric waves**) are reflected by the ionosphere and enable long-distance transmissions to be made. The ionization of atoms and molecules in the ionosphere is caused largely by solar ultraviolet and X-radiation and therefore conditions differ between night and day. Ionization in the lower E-region of the ionosphere falls off at night in the absence of sunlight and ions and electrons tend to recombine. However, in the less dense (higher) F-region there are fewer collisions between ions and electrons and therefore fewer recombinations at night. The F-region is therefore a more effective reflector at night.

The UHF and VHF waves used in television broadcasting penetrate the ionosphere with little reflection. Therefore TV broadcasts can only be made over long distances by means of artificial satellites. *See also* RADIO.

radiotransparent Transparent to radiation, especially to X-rays and gamma-rays.

radio window A region of the electromagnetic spectrum in the radio-frequency band within which radio waves can be transmitted through the earth's atmosphere without significant reflection or attenuation by constituents of the atmosphere. It extends from about 10 megahertz to 100 gigahertz and enables radiation in this range from celestial radio sources to be picked up by *radio telescopes on the earth's surface. Below 100 MHz incoming radio waves are reflected by the ionosphere and those above 100 GHz are increasingly affected by molecular absorption.

radium Symbol Ra. A radioactive metallic element belonging to *group 2 (formerly IIA) of the periodic table; a.n. 88; r.a.m. 226.0254; r.d. ~5; m.p. 700°C; b.p. 1140°C. It occurs in uranium ores (e.g. pitchblende). The most stable isotope is radium–226 (half-life 1602 years), which decays to radon. It is used as a radioactive source in research and, to some extent, in radiotherapy. The element was isolated from pitchblende in 1898 by Marie and Pierre Curie.

SEE WEB LINKS

- Information from the WebElements site

radius **1.** (in anatomy) The smaller of the two bones in the lower section of the forelimb of a tetrapod vertebrate (*compare* ULNA). The radius articulates with some carpal bones and the ulna at the wrist and with the *humerus at the elbow. This sophisticated articulation of the radius enables humans (and some other animals) to twist the forearm (*see* PRONATION; SUPINATION). **2.** (in mathematics) *See* CIRCLE.

radius of curvature *See* CENTRE OF CURVATURE.

radius of gyration Symbol k. The square root of the ratio of the *moment of inertia of a rigid body about an axis to the body's mass, i.e. $k^2 = I/m$, where I is the body's moment of inertia and m is its mass. If a rigid body has a moment of inertia I about an axis and mass m it behaves as if all its mass is rotating at a distance k from the axis.

radius vector *See* POLAR COORDINATES.

radon Symbol Rn. A colourless radioactive gaseous element belonging to group 18 of the periodic table (the *noble gases); a.n. 86; r.a.m. 222; d. 9.73 g dm^{-3}; m.p. –71°C; b.p. –61.8°C. At least 20 isotopes are known, the most stable being radon–222 (half-life 3.8 days). It is formed by decay of radium–226 and undergoes alpha decay. It is used in radiotherapy. Radon occurs naturally, particularly in areas underlain by granite, where it is thought to be a health hazard. As a noble gas, radon is practically inert, although a few compounds, e.g. radon fluoride, can be made. It was first isolated by William Ramsey and Robert Whytlaw-Gray (1877–1958) in 1908.

SEE WEB LINKS

- Information from the WebElements site

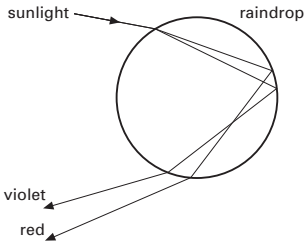
radula A tonguelike organ of molluscs, consisting of a horny strip whose surface is studded with rows of horny teeth for rasping food. In some species it is modified for scraping or boring.

raffinate A liquid purified by solvent extraction.

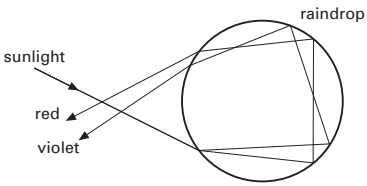
raffinose A white solid carbohydrate, $C_{18}H_{32}O_{16}$, m.p. 80°C. It is a trisaccharide (a type of *sugar) consisting of fructose, galactose and glucose. It occurs naturally in sugar-beet and cotton-seed residues.

rainbow An optical phenomenon that appears as an arc of the colours of the spectrum across the sky when falling water droplets are illuminated by sunlight from behind the observer. The colours are produced

by the refraction and internal reflection of the sunlight by the water drops. Two bows may be visible, the inner ring being known as the primary bow and the outer, in which the colours are reversed, as the secondary bow.



Primary rainbow (one internal reflection)



Secondary rainbow (two internal reflections)

Rainbow.

rainfall *See* PRECIPITATION.

rainforest Any major terrestrial *biome in which trees form the dominant plants and annual rainfall is high (over 200 cm). Tropical rainforest is restricted to equatorial regions, such as the Amazon basin, central west Africa, and SE Asia. It is dominated by broadleaved evergreens and shows a very rich species diversity (*see* BIODIVERSITY). The leafy crowns of the trees typically form three layers of canopy, since the trees grow to different heights, which prevents much sunlight from reaching ground level. This limits the number of herbaceous plants and small shrubs that grow on the forest floor, but *epiphytes, vines, and creepers are abundant. The average temperature is about 27°C, which – together with the high humidity – encourages rapid decomposition of leaf litter, releasing minerals that replace those leached from the soil by the heavy rain. If the forest canopy is removed, the soil is destroyed rapidly due to leaching by rain. The soil of a rainforest, known as **latosol**, is acidic and typically red, due to the oxidation of iron oxide (Fe_2O_3) in the topsoil. Rainforests are thought to contain many undiscovered plant species that could be of benefit in the fields of medicine and biotechnology. The continued destruction of rainforest in many parts of the world, particularly in South America and SE Asia (*see* DEFORESTATION), will not only result in the loss of these and other species but also contributes to the *greenhouse effect.

SEE WEB LINKS

- Website for Rainforest Action Network, an international organization that campaigns to protect the rainforests

RAM Random-access memory. The main memory of a computer, fabricated from *integrated circuits, in which data can only be stored temporarily – until the power supply is turned off. RAM consists of arrays of 'cells', each capable of holding one *bit of data. Cells are completely independent so that the access time to any location is fixed (and extremely rapid) hence the term random access.

r.a.m. *See* RELATIVE ATOMIC MASS.

Raman effect A type of inelastic *scattering of light and ultraviolet radiation discovered in 1928 by Chandrasekara Raman (1880–1970). If a beam of monochromatic light is passed through a transparent substance some of the radiation will be scattered. Although most of the scattered radiation will be the same as the incident frequency, some will have frequencies above (anti-Stokes radiation) and below (Stokes radiation) that of the incident beam. This effect is known as **Raman scattering** and is due to inelastic collisions between photons and molecules leading to changes in the vibrational and rotational energy levels of the molecules. An increase in frequency represents a loss in molecular energy; a decrease represents a gain in molecular energy.

This effect is used in **Raman spectroscopy** for investigating the vibrational and rotational energy levels of molecules. Because the scattering intensity is low, a laser source is used.

SEE WEB LINKS

- The original paper in *Nature* (1928) by Raman and Krishnan

Ramapithecus *See* SIVAPITHECUS.

ramjet *See* JET PROPULSION.

Ramón y Cajal, Santiago *See* GOLGI, CAMILLO.

Ramsay, Sir William (1852–1916) British chemist, born in Glasgow. After working under Robert *Bunsen, he returned to Glasgow before taking up professorships at Bristol (1880–87) and London (1887–1912). In the early 1890s he worked with Lord *Rayleigh on the gases in air and in 1894 they discovered *argon. In 1898, with Morris Travers (1872–1961), he discovered *neon, *krypton, and *xenon. Six years later he discovered the last of the noble gases, *radon. He was awarded the Nobel Prize for chemistry in 1904, the year in which Rayleigh received the physics prize.

Ramsden eyepiece An eyepiece for optical instruments consisting of two identical plano-convex lenses with their convex faces pointing towards each other. They are separated by a distance of two thirds of the focal length of either lens.

Randall–Sundrum scenario A variant of the *brane world picture in which gravity is trapped by warping of the higher dimensions. This scenario, put forward by the American physicist Lisa Randall (1962–) and Raman Sundrum in 1999, has attracted a great deal of interest because it provides a possible explanation of why gravity is weaker than the other forces.

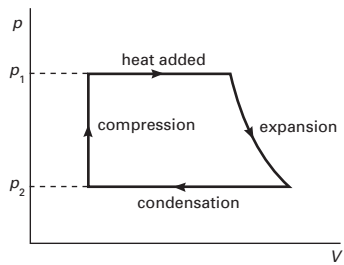
random alloy *See* DISORDERED SOLID.

random walk The problem of determining the distance from a starting position made by a walker, who can either move forward (toward $+x$) or backwards (toward $-x$) with the choice being made randomly (e.g. by tossing a coin). The progress of the walker is characterized by the net distance D_N travelled in N steps. After N steps the *root mean square value D_{rms}, which is the average distance away from the starting position, is given by $D_{rms} = \sqrt{N}$. Physical applications of the random walk include diffusion and the related problem of Brownian motion as well as problems involving the structures of polymers and disordered solids.

Raney nickel A spongy form of nickel made by the action of sodium hydroxide on a nickel–aluminium alloy. The sodium hydroxide dissolves the aluminium leaving a highly active form of nickel with a large surface area. The material is a black pyrophoric powder saturated with hydrogen. It is an extremely efficient catalyst, especially for hydrogenation reactions at room temperature. It was discovered in 1927 by the American chemist M. Raney.

rank (category) (in biology) The position or status of a *taxon in a *classification hierarchy. Examples of ranks are the family, genus, and species.

Rankine cycle A cycle of operations in a heat engine. The Rankine cycle more closely approximates to the cycle of a real steam engine that does the *Carnot cycle. It therefore predicts a lower ideal thermal efficiency than the Carnot cycle. In the Rankine cycle (see illustration), heat is added at constant pressure p_1, at which water is converted in a boiler to superheated steam; the steam expands at constant entropy to a pressure p_2 in the cylinder; heat is rejected at constant pressure p_2 in a condenser; the water so formed is compressed at constant entropy to pressure p_1 by a feed pump. The cycle was devised by William Rankine (1820–70).



Rankine cycle.

Rankine temperature scale An absolute temperature scale based on the Fahrenheit scale. Absolute zero on this scale, 0°R, is equivalent to –459.67°F and the melting point of ice (32°F) is therefore (459.67 + 32 = 491.67)°R. The scale was devised by William Rankine.

ranksite A mineral consisting of a mixed sodium carbonate, sodium sulphate, and potassium chloride, $2Na_2CO_3.9Na_2SO_4.KCl$.

Raoult's law The partial vapour pressure of a solvent is proportional to its mole fraction. If p is the vapour pressure of the solvent (with a substance dissolved in it) and X the mole fraction of solvent (number of moles of solvent divided by total number of moles) then $p = p_0X$, where p_0 is the vapour pressure of the pure solvent. A solution that obeys

Raoult's law is said to be an **ideal solution**. In general the law holds only for dilute solutions, although some mixtures of liquids obey it over a whole range of concentrations. Such solutions are **perfect solutions** and occur when the intermolecular forces between molecules of the pure substances are similar to the forces between molecules of one and molecules of the other. Deviations in Raoult's law for mixtures of liquids cause the formation of *azeotropes. The law was discovered by the French chemist François Raoult (1830–1901).

SEE WEB LINKS

- Raoult's original paper in *Comptes Rendus* (1887)

rapeseed methyl ester *See* BIOFUEL.

rare-earth elements *See* LANTHANOIDS.

rarefaction A reduction in the pressure of a fluid and therefore of its density.

rare gases *See* NOBLE GASES.

RAS *See* REFLECTION ANISOTROPY SPECTROSCOPY.

Raschig process An industrial process for making chlorobenzene (and phenol) by a gas-phase reaction between benzene vapour, hydrogen chloride, and oxygen (air) at 230°C

$$2C_6H_6 + 2HCl + O_2 \rightarrow 2H_2O + 2C_6H_5Cl$$

The catalyst is copper(II) chloride. The chlorobenzene is mainly used for making phenol by the reaction

$$C_6H_5Cl + H_2O \rightarrow HCl + C_6H_5OH$$

This reaction proceeds at 430°C with a silicon catalyst. The process was invented by the German chemist Fritz Raschig (1863–1928).

Raschig synthesis *See* HYDRAZINE.

RasMol A commonly used program for visualizing molecules. It can be used with a range of file formats and the display can be choosen (e.g. wireframe, ball-and-stick, space filling, etc.). The original version was written by Roger Sayle of Glaxo around 1990. It is freely available.

SEE WEB LINKS

- A downloadable version of RasMol from the website of the University of Massachusetts Amherst

raster The pattern of scanning lines on the screen of the cathode-ray tube in a television receiver or other device that provides a visual display.

rate constant (velocity constant) Symbol k. The constant in an expression for the rate of a chemical reaction in terms of concentrations (or activities). For instance, in a simple unimolecular reaction

$$A \rightarrow B$$

the rate is proportional to the concentration of A, i.e.

$$\text{rate} = k[A]$$

where k is the rate constant, which depends on the temperature. The equation is the **rate equation** of the reaction, and its form depends on the reaction mechanism.

rate-determining step The slowest step in a chemical reaction that involves a number of steps. In such reactions, there is often a single step that is appreciably slower than the other steps, and the rate of this determines the overall rate of the reaction.

rationalized Planck constant *See* PLANCK CONSTANT.

rationalized units A system of units in which the defining equations have been made to conform to the geometry of the system in a logical way. Thus equations that involve circular symmetry contain the factor 2π, while those involving spherical symmetry contain the factor 4π. *SI and *Heaviside–Lorentz units are rationalized; *Gaussian units are unrationalized.

rational number Any number that can be expressed as the ratio of two integers. For example, 0.3333… is rational because it can be written as 1/3. $\sqrt{2}$, however, is *irrational.

Ratitae (Palaeognathae) A group comprising the flightless birds, including the ostrich, kiwi, and emu. They have long legs, heavy bones, small wings, a flat breastbone, and curly feathers. These birds are thought to have descended from a variety of flying birds and are not representatives of a single homologous group.

ray **1.** (in optics) A narrow beam of radiation or an idealized representation of such a beam on a **ray diagram**, which can be used to indicate the positions of the object and image in a system of lenses or mirrors. **2.** (in botany) *See* MEDULLARY RAY.

Rayleigh, Baron (John William Strutt; 1842–1919) British physicist, who built a private laboratory after working at Cambridge

University. His work in this laboratory included the discovery of Rayleigh *scattering. He also worked in acoustics, electricity, and optics, as well as collaborating with William *Ramsay on the discovery of *argon. He was awarded the 1904 Nobel Prize for physics.

Rayleigh criterion *See* RESOLVING POWER.

Rayleigh–Jeans formula *See* PLANCK'S RADIATION LAW.

Rayleigh scattering *See* SCATTERING OF ELECTROMAGNETIC RADIATION.

rayon A textile made from cellulose. There are two types, both made from wood pulp. In the viscose process, the pulp is dissolved in carbon disulphide and sodium hydroxide to give a thick brown liquid containing cellulose xanthate. The liquid is then forced through fine nozzles into acid, where the xanthate is decomposed and a cellulose filament is produced. The product is **viscose rayon**. In the acetate process cellulose acetate is made and dissolved in a solvent. The solution is forced through nozzles into air, where the solvent quickly evaporates leaving a filament of **acetate rayon**.

RBS *See* RUTHERFORD BACKSCATTERING SPECTROMETRY.

RDX *See* CYCLONITE.

reactance Symbol X. A property of a circuit containing inductance or capacitance that together with any resistance makes up its *impedance. The impedance Z is given by $Z^2 = R^2 + X^2$, where R is the resistance. For a pure capacitance C, the reactance is given by $X_C = 1/2\pi fC$, where f is the frequency of the *alternating current; for a pure inductance L, $X_L = 2\pi fL$. If the resistance, inductance, and capacitance are in series the impedance $Z = \sqrt{[R^2 + (X_L - X_C)^2]}$. Reactance is measured in ohms.

reactant *See* CHEMICAL REACTION.

reaction **1.** A force that is equal in magnitude but opposite in direction to some other force, in accordance with Newton's third law of motion. If a body A exerts a force on body B, then B exerts an equal and opposite force on A. Thus, every force could be described as 'a reaction', and the term is better avoided, although it is still used in such terms as 'reaction propulsion'. **2.** *See* CHEMICAL REACTION.

reaction propulsion *See* JET PROPULSION.

reaction time (latent period) The period of time between the detection of a stimulus at a sensory receptor and the performance of the appropriate response by the effector organ. This delay is caused by the time taken for the impulse to travel across the synapses of adjacent neurons. The reaction time for a *reflex response, involving only a single linking synapse, is very short.

reactive dye *See* DYES.

reactive oxygen species (ROS) Any of various chemical species that contain highly active oxygen, particularly the *free radical superoxide anion (O_2^-) and its derivatives, including hydrogen peroxide (H_2O_2), singlet oxygen (a metastable high-energy form of molecular oxygen), hydroxyl radical (OH·), and hypohalite ions (e.g. hypochlorite, OCl^-). Superoxide is produced normally as a by-product of aerobic respiration inside mitochondria; both it and other ROS are potentially harmful to living cells because of their highly reactive nature. They can damage DNA and other cell components and are implicated in various diseases (e.g. cancer, heart disease), hence cells have an array of mechanisms to remove them, including the enzyme superoxide dismutase and various *antioxidants. However, certain cells and tissues in both plants and animals produce ROS in order to destroy invading pathogenic organisms, such as fungi and bacteria.

reactor **1.** *See* NUCLEAR REACTOR. **2.** Any device, such as an inductor or capacitor, that introduces *reactance into an electrical circuit.

reading frame A sequence of bases in messenger RNA (or deduced from DNA) that encodes for a polypeptide. Since each coding unit (*codon) of the genetic code consists of three consecutive bases, the reading frame is established according to precisely where translation starts. The hallmark of a functional gene is that it is transcribed to produce an **open reading frame** (**ORF**), consisting of a *start codon to pinpoint where translation should start, a *stop codon to signal termination of translation, and typically a long sequence of codons that specify the constituent amino acids of the polypeptide (as well as *introns in most eukaryote genes).

reagent A substance reacting with another substance. Laboratory reagents are compounds, such as sulphuric acid, hydrochloric

acid, sodium hydroxide, etc., used in chemical analysis or experiments.

realgar A red mineral form of arsenic(II) sulphide, As_2S_2.

real gas A gas that does not have the properties assigned to an *ideal gas. Its molecules have a finite size and there are forces between them (*see* EQUATION OF STATE).

real image *See* IMAGE.

real-is-positive convention (real-positive convention) A convention used in optical formulae relating to lenses and mirrors. In this convention, distances from optical components to real objects, images, and foci are taken as positive, whereas distances to virtual points are taken as negative.

rearrangement A type of chemical reaction in which the atoms in a molecule rearrange to form a new molecule.

Réaumur temperature scale A temperature scale in which the melting point of ice is taken as 0°R and the boiling point of water as 80°R. It was devised by René Antoine Réaumur (1683–1757).

recalescence A phenomenon that occurs during the cooling of iron and other ferromagnetic metals (*see* MAGNETISM) after they have been heated. When iron is heated to white heat and then allowed to cool, it abruptly evolves heat at a certain temperature. This evolution of heat, which slows down the cooling process and can lead to a brief reheating, is caused by an *exothermic reaction when the structure of the crystal changes. The temperature at which this occurs is called the **recalescence point**. For pure iron there are two recalescence points: at 780°C and 880°C. A reverse phenomenon causing cooling, called **decalescence**, occurs when ferromagnetic metals are heated.

Recent *See* HOLOCENE.

receptacle **1. (thalamus; torus)** The tip of a flower stalk, which bears the petals, sepals, stamens, and carpels. The way the receptacle develops determines the position of the flower parts. It can be dilated and dome-shaped, saucer-shaped, or hollow and enclosing the gynoecium. In some plants it may become part of the fruit (*see* PSEUDOCARP). **2.** A swollen part of the thallus of some algae, e.g. *Fucus*, that bears the conceptacles in which the sex organs are situated.

receptor (in biology) **1.** A cell or group of cells specialized to detect a particular stimulus and to initiate the transmission of impulses via the sensory nerves. The eyes, ears, nose, skin, and other sense organs all contain specific receptors responding to external stimuli (*see* EXTEROCEPTOR); other receptors are sensitive to changes within the body (*see* INTEROCEPTOR). *See also* BARORECEPTOR; CHEMORECEPTOR; MECHANORECEPTOR; OSMORECEPTOR; PROPRIOCEPTOR. **2.** An area of a plasma membrane, consisting of a specially adapted membrane protein, that can bind with a specific hormone, neurotransmitter, drug, or other chemical, thereby initiating a change within the cell.

recessive The *allele that is not expressed in the *phenotype when two different alleles are present in the cells of an organism. The aspect of a characteristic controlled by a recessive allele only appears when two such alleles are present, i.e. in the **double recessive** condition. *Compare* DOMINANT.

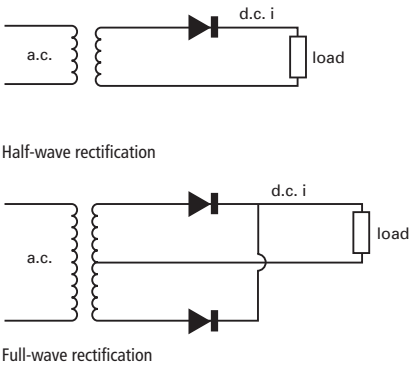
recipient An individual who receives tissues or organs of the body from another (the *donor).

reciprocal cross A *cross reversing the roles of males and females to confirm the results obtained from an earlier cross. For example, if the pollen (male) from tall plants is transferred to the stigmas (female) of dwarf plants in one cross, the reciprocal cross would use the pollen of dwarf plants to pollinate the stigmas of tall plants.

reciprocal proportions *See* CHEMICAL COMBINATION.

recombinant DNA DNA that contains genes from different sources that have been combined by the techniques of *genetic engineering rather than by breeding experiments. Genetic engineering is therefore also known as **recombinant DNA technology**. Recombinant DNA is formed during *gene cloning and in the creation of *genetically modified organisms.

recombination The rearrangement of genes that occurs when reproductive cells (gametes) are formed. It results from the *independent assortment of parental sets of chromosomes and exchange of chromosomal material (*see* CROSSING OVER) that occur during *meiosis. Recombination results in offspring that have a combination of characteristics different from that of their parents.



Rectifier.

Recombination can also be induced artificially by *genetic engineering techniques.

recombination era The period after the big bang when the universe was sufficiently cool for electrons and nuclei to form atoms for the first time. The recombination occurred about 300 000 years after the big bang. Up to this time, photons in the universe were scattered by free electrons and it is sometimes said that the universe was 'opaque'. With recombination, photons were able to travel without impediment, and the universe became 'transparent'. *See also* MICROWAVE BACKGROUND RADIATION.

recombination process The process in which a neutral atom or molecule is formed by the combination of a positive ion and a negative ion or electron; i.e. a process of the type:

$A^+ + B^- \rightarrow AB$

or

$A^+ + e^- \rightarrow A$

In recombination, the neutral species formed is usually in an excited state, from which it can decay with emission of light or other electromagnetic radiation.

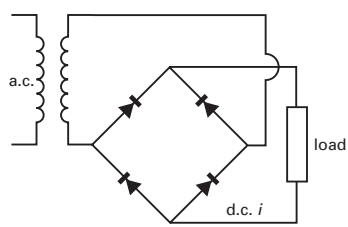
recreational drug A drug used for recreation, as opposed to medical use. Strictly, recreational drugs include alcohol and nicotine, but the term is often understood to mean substances such as marijuana, cocaine, and amphetamines.

recrystallization A process of repeated crystallization in order to purify a substance or to obtain more regular crystals of a purified substance.

rectification **1.** (in physics) The process of obtaining a direct current from an alternating electrical supply. *See* RECTIFIER. **2.** (in chemistry) The process of purifying a liquid by *distillation. *See* FRACTIONAL DISTILLATION.

rectified spirit A constant-boiling mixture of *ethanol (95.6°) and water; it is obtained by distillation.

rectifier An electrical device that allows more current to flow in one direction than the other, thus enabling alternating e.m.f.s to drive only direct current. The device most commonly used for rectification is the semiconductor *diode. In **half-wave rectification**, achieved with one diode, a pulsating current is produced. In **full-wave rectification** two diodes are used, one pair conducting during the first half cycle and the other conducting during the second half (see illustration). The full-wave rectified signal can be smoothed using a capacitor or an inductor.



Rectifier. Bridge rectifier.

The **bridge rectifier** illustrated also gives full-wave rectification.

rectum The portion of the *alimentary canal between the *colon and the *anus. Its main function is the storage of *faeces prior to elimination.

recycling **1.** The recovery and processing of materials after they have been used, which enables them to be reused. For example, used paper, cans, and glass can be broken down into their constituents, which form the raw materials for the manufacture of new products. **2.** The continual movement of *essential elements between the biotic (living) and abiotic (nonliving) components of the environment. *See* CARBON CYCLE; NITROGEN CYCLE; OXYGEN CYCLE; PHOSPHORUS CYCLE; SULPHUR CYCLE.

red algae *See* RHODOPHYTA.

red blood cell *See* ERYTHROCYTE.

red dwarf A *dwarf star on the main sequence (*see* HERTZSPRUNG–RUSSELL DIAGRAM) that is much cooler, smaller, and less massive than the sun. These stars display a number of magnetic phenomena. *See also* FLARE STAR.

red giant A *giant star thought to be in the later stages of *stellar evolution. It has a surface temperature in the range 2000–3000 K and a diameter 10–100 times that of the sun. *See also* HERTZSPRUNG–RUSSELL DIAGRAM.

red lead *See* DILEAD(II) LEAD(IV) OXIDE.

redox *See* OXIDATION–REDUCTION.

redshift **1. (Doppler redshift)** A displacement of the lines in the spectra of certain galaxies towards the red end of the visible spectrum (i.e. towards longer wavelengths). It is usually interpreted as a *Doppler effect resulting from the recession of the galaxies along the line of sight (*see* EXPANSION OF THE UNIVERSE). The redshift is usually expressed as $\Delta\lambda/\lambda$, where $\Delta\lambda$ is the shift in wavelength of radiation of wavelength λ. For relatively low velocities of recession this is equivalent to v/c, where v is the relative velocity of recession and c is the speed of light. If very high velocities of recession are involved, a relativistic version of v/c is required (*see* RELATIVISTIC SPEED). The redshift of spectral lines occurs in all regions of the electromagnetic spectrum; ultraviolet can be shifted into the visible region and visible radiation can be shifted into the infrared region.

2. (gravitational *or* Einstein redshift) A similar displacement of spectral lines towards the red caused not by a Doppler effect but by a high gravitational field. This type of redshift was predicted by Einstein and some astronomers believe that this is the cause of the large redshifts of *quasars, which can be as high as 6.4.

reducing agent (reductant) A substance that brings about reduction in other substances. It achieves this by being itself oxidized. Reducing agents contain atoms with low oxidation numbers; that is the atoms have gained electrons. In reducing other substances, these atoms lose electrons.

reducing sugar A monosaccharide or disaccharide sugar that can donate electrons to other molecules and can therefore act as a reducing agent. The possession of a free ketone (–CO–) or aldehyde (–CHO) group enables most monosaccharides and disaccharides to act as reducing sugars. Reducing sugars can be detected by *Benedict's test. *Compare* NONREDUCING SUGAR.

reductant *See* REDUCING AGENT.

reduction *See* OXIDATION–REDUCTION.

reduction division *See* MEIOSIS.

reef An outcrop of rock that projects above the surface in shallow seas, particularly one constructed by calcareous animals, such as *corals, shellfish, and some algae. Reefs may be mounds or ridges, often with very steep sides, or even a chain of islands. A fringing reef is attached to the coast and acts as a breakwater; a barrier reef runs parallel to the coast, usually with a deeper lagoon on the landward side. Reefs provide rich habitats for fish and invertebrates. *See also* ATOLL.

refinery gas *See* PETROLEUM.

refining The process of purifying substances or extracting substances from mixtures.

reflectance The ratio of the radiant flux reflected by a surface to that falling on it. This quantity is also known as the **radiant reflectance**. The radiant reflectance measured for a specified wavelength of the incident radiant flux is called the **spectral reflectance**.

reflecting telescope (reflector) *See* TELESCOPE.

reflection The return of all or part of a

beam of particles or waves when it encounters the boundary between two media. The **laws of reflection** state: (1) that the incident ray, the reflected ray, and the normal to the reflecting interface at the point of incidence are all in the same plane; (2) that the angle of incidence equals the angle of reflection. *See also* MIRROR; REFLECTANCE; TOTAL INTERNAL REFLECTION.

reflection anisotropy spectroscopy (RAS) A spectroscopic technique for studying surfaces by reflection of light or ultraviolet radiation. A beam of plane-polarized monochromatic radiation is directed at right angles onto a single-crystal surface and the reflected radiation along the surface is measured in two mutually perpendicular directions. If a suitable surface plane is chosen, there is a difference in reflectivity in these directions – a reflection anisotropy – and for a cubic crystal this is a property of the surface rather than the bulk. The change in this effect with wavelength gives a reflection anisotropy spectrum, which gives information about electronic surface states. Surface reactions can be investigated by the changes they cause in the spectrum.

reflex An automatic and innate response to a particular stimulus. A reflex response is extremely rapid. This is because it is mediated by a simple nervous circuit called a **reflex arc**, which at its simplest involves only a receptor linked to a sensory neuron, which synapses with a motor neuron (supplying the effector) in the spinal cord. Such reflexes are known as **spinal reflexes**; examples are the **withdrawal reflex** of the hand from a painful stimulus (such as fire) and the *stretch reflex. **Cranial reflexes** are mediated by pathways in the cranial nerves and brain; examples are the blinking and swallowing reflexes. *See also* CONDITIONING.

refluxing A laboratory technique in which a liquid is boiled in a container attached to a condenser (**reflux condenser**), so that the liquid continuously flows back into the container. It is used for carrying out reactions over long periods in organic synthesis.

reforestation The replanting of trees on areas of land where forests have been cleared by felling or burning (*see* DEFORESTATION) or by natural means. Reforestation is particularly important in countries, such as Brazil, where large areas of forest have been destroyed by deforestation, although planted forest has much less species diversity (*see* BIODIVERSITY) than the original forest. It also helps to counteract global emissions of carbon dioxide, by fixing the gas as plant material. Hence reforestation can play a part in slowing *global warming.

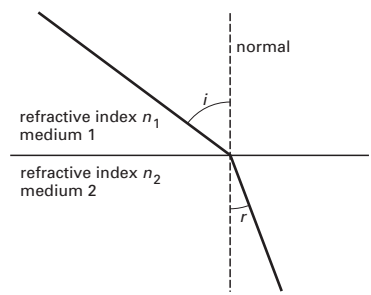
reforming The conversion of straight-chain alkanes into branched-chain alkanes by *cracking or by catalytic reaction. It is used in petroleum refining to produce hydrocarbons suitable for use in gasoline. Benzene is also manufactured from alkane hydrocarbons by catalytic reforming. **Steam reforming** is a process used to convert methane (from natural gas) into a mixture of carbon monoxide and hydrogen, which is used to synthesize organic chemicals. The reaction

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

occurs at about 900°C using a nickel catalyst.

refracting telescope (refractor) *See* TELESCOPE.

refraction The change of direction suffered by wavefront as it passes obliquely from one medium to another in which its speed of propagation is altered. The phenomenon occurs with all types of waves, but is most familiar with light waves. In optics the direction is changed in accordance with **Snell's law**, i.e. $n_1 \sin i = n_2 \sin r$, where i and r are the angles made by the incident beam of radiation and the refracted beam to the normal (an imaginary line perpendicular to the interface between the two media); n_1 and n_2 are the *refractive indices of the two media. This law is also known as one of the **laws of refraction**. The other law of refraction is that the incident ray, the refracted ray, and the normal at the point of incidence lie in the same plane. The change of direction results from a change in the speed of propagation



Refraction.

and the consequent change in wavelength (see illustration).

refractive index (refractive constant) Symbol *n*. The **absolute refractive index** of a medium is the ratio of the speed of electromagnetic radiation in free space to the speed of the radiation in that medium. As the refractive index varies with wavelength, the wavelength should be specified. It is usually given for yellow light (sodium D-lines; wavelength 589.3 nm). The **relative refractive index** is the ratio of the speed of light in one medium to that in an adjacent medium. *See also* REFRACTION.

refractivity A measure of the extent to which a medium will deviate a ray of light entering its surface. In some contexts it is equal to $(n - 1)$, where n is the *refractive index.

refractometer Any of various instruments for measuring the *refractive index of a substance or medium. An example is the **Pulfrich refractometer**, which is a glass block with a polished top, with a small cell on top of the block for liquid samples. A telescope rotating on a vertical circular scale is used to find the angle (α) between the top of the block and the direction in which the limiting ray (from incident light parallel to the top face) leaves the side of the block. If the refractive index of the block (n_g) is known, that of the liquid can be calculated using $n = \sqrt{(n_g^2 - \sin^2\alpha)}$.

refractory **1.** Having a high melting point. Metal oxides, carbides, and silicides tend to be refractory, and are extensively used for lining furnaces. **2.** A refractory material.

refractory period The period after the transmission of an impulse in a nerve or muscle in which the membrane of the axon or muscle fibre regains its ability to transmit impulses (*see* ACTION POTENTIAL). This period lasts approximately 3 milliseconds and is divided into an **absolute refractory period**, during which a second impulse may not be generated; and a **relative refractory period**, during which it is possible to generate an impulse only if there is an abnormally strong stimulus.

refrigerant *See* REFRIGERATION.

refrigeration The process of cooling a substance and of maintaining it at a temperature below that of its surroundings. See Feature overleaf.

regeneration The growth of new tissues or organs to replace those lost or damaged by injury. Many plants can regenerate a complete plant from a shoot segment or a single leaf, this being the basis of many horticultural propagation methods (*see* CUTTING). The capacity for regeneration in animals is less marked. Some planarians and sponges can regenerate whole organisms from small pieces, and crustaceans (e.g. crabs), echinoderms (e.g. brittlestars), and some reptiles and amphibians can grow new limbs or tails (*see* AUTOTOMY), but in mammals regeneration is largely restricted to wound healing and, in certain cases, regrowth of damaged nerve fibres.

regioselectivity The effect in which certain positions in the molecule are favoured over others in a reaction. An example is the way in which certain groups on the benzene ring direct further substituents to the meta position or to the ortho and para positions. *Markovnikoff's rule for electrophilic additions to alkenes is another example.

regma A dry fruit that is characteristic of the geranium family. It is similar to the *carcerulus but breaks up into one-seeded parts, each of which splits open to release a seed.

Regnault's method A technique for measuring gas density by evacuating and weighing a glass bulb of known volume, admitting gas at known pressure, and reweighing. The determination must be carried out at constant known temperature and the result corrected to standard temperature and pressure. The method is named after the French chemist Henri Victor Regnault (1810–78).

regolith A layer of weathered rock fragments that lies below the soil and above the bedrock below. In the tropics it may be up to 60 m thick. Fine regolith differs from soil in that it has no organic content (humus) and cannot therefore support plant life, although the roots of trees and other plants may penetrate it for water.

regulator gene *See* OPERON.

regulatory genes Genes that control development by regulating the expression of structural genes responsible for the formation of body components. They encode *transcription factors, which interact with regulatory sites of other genes causing activation or repression of developmental path-

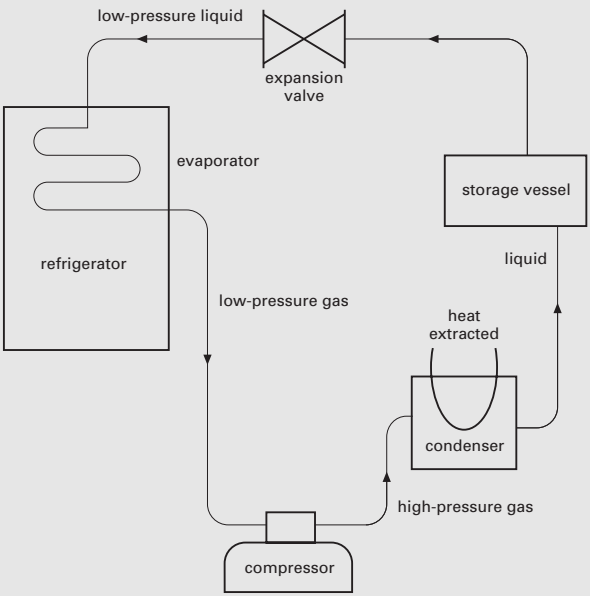
REFRIGERATION

In the domestic refrigerator a cycle of operations equivalent to those of a *heat pump is used.

The vapour-compression cycle

In this cycle (see illustration) a volatile liquid refrigerant, such as a fluorocarbon, is pumped through the cooling coils of the evaporator to the ice-making compartment of the refrigerator. Inside these coils the refrigerant evaporates, taking the latent heat required to effect the change of state from the inside of the ice-making compartment, causing the temperature in this compartment to fall. The vapour is then passed to an electrically driven compressor before entering the condenser, where the high-pressure gas is converted back to a liquid. The heat produced by this second change of state is given out, usually at the back of the refrigerator. The liquid refrigerant then enters a storage vessel before finally passing through an expansion valve to reduce its pressure prior to beginning the cycle again in the evaparator.

This cycle is repeated over and over again until the temperature reaches the desired level (about 1–2°C in the food chamber of a domestic refrigerator and minus 15–18°C in the deep-freeze compartment). The compressor is then switched off, and on again later, by a thermostat to maintain a steady temperature. In order to transfer heat from the cold interior to the warm surroundings without contravening the second law of thermodynamics, energy has to be supplied to the cycle by the electric current that drives the compressor.



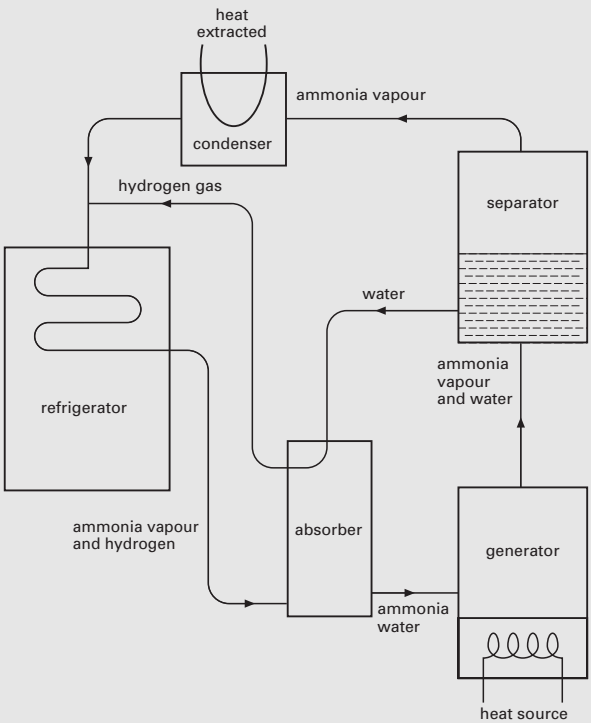
Vapour-compression cycle

The vapour-absorption cycle

In this cycle there are no moving parts and energy is supplied as heat either by an electric heater or a gas burner. The refrigerant is usually ammonia, which is liberated from a water solution and moved through the evaporator by a stream of hydrogen gas under pressure. Heat is applied to the generator, raising the ammonia and water vapour to the separator; the ammonia separates from the water and passes to the condenser, where it cools and liquefies, giving off its latent heat to the surroundings. The liquid ammonia is then mixed with hydrogen gas, which carries it through the evaporator and helps in the process of evaporation. Subsequently the hydrogen and ammonia vapour enter the absorber, where the water returned from the separator dissolves the ammonia before returning to the generator.

Small-scale refrigerator

These two systems account for all domestic and industrial refrigerators including those on in ships, trains, and refrigerated lorries. However, small-scale refrigeration is sometimes achieved by means of the *Peltier effect at junctions for *n*-type and *p*-type semiconductors.



Vapour-absorption cycle

ways. Much of development in quite different organisms, such as mammals and insects, is controlled by genes that are structurally very similar, thought to descended from genes in ancient common ancestors. Prime examples are the *homeotic genes.

Reines, Frederick *See* PAULI, WOLFGANG ERNST.

reinforcement (in animal behaviour) Increasing (or decreasing) the frequency of a particular behaviour through *conditioning, by arranging for some biologically important event (the **reinforcer**) always to follow another event. In instrumental conditioning an **appetitive reinforcer**, or **reward** (e.g. food), given after a response made by the animal, increases that response; an **aversive reinforcer**, or **punishment** (e.g. an electric shock) decreases the response.

relational theory A type of theory in which *absolute space and *absolute time do not occur, with the theory depending on relationships between events. Newtonian mechanics is not a relational theory but the general theory of relativity is nearer to being a relational theory. A theory that fully incorporated *Mach's principle would be a relational theory.

relative aperture *See* APERTURE.

relative atomic mass (atomic weight; r.a.m.) Symbol A_r. The ratio of the average mass per atom of the naturally occurring form of an element to 1/12 of the mass of a carbon–12 atom.

SEE WEB LINKS

- Values of r.a.m. at the NIST website

relative density (r.d.) The ratio of the *density of a substance to the density of some reference substance. For liquids or solids it is the ratio of the density (usually at 20°C) to the density of water (at its maximum density). This quantity was formerly called **specific gravity**. Sometimes relative densities of gases are used; for example, relative to dry air, both gases being at s.t.p.

relative humidity *See* HUMIDITY.

relative molecular mass (molecular weight) Symbol M_r. The ratio of the average mass per molecule of the naturally occurring form of an element or compound to 1/12 of the mass of a carbon–12 atom. It is equal to the sum of the relative atomic masses of all the atoms that comprise a molecule.

relative permeability *See* PERMEABILITY.

relative permittivity *See* PERMITTIVITY.

relativistic electronics A branch of *electronics that involves the special theory of relativity. The *free-electron laser is an example of an application in relativistic electronics.

relativistic jets Jets of matter or electromagnetic radiation that move away from some *active galaxies at very large speeds. It is thought that the energy for these jets is supplied by the activity around black holes, either through a *Blandford–Znajek process or through a *Penrose process.

relativistic mass The mass of a moving body as measured by an observer in the same frame of reference as the body. According to the special theory of *relativity the mass m of a body moving at speed v is given by $m = m_0/\sqrt{(1 - v^2/c^2)}$, where m_0 is its *rest mass and c is the speed of light. The relativistic mass therefore only differs significantly from the rest mass if its speed is a substantial fraction of the speed of light. If $v = c/2$, for example, the relativistic mass is 15% greater than the rest mass.

relativistic mechanics An extension of Newtonian mechanics that takes into account the theory of *relativity.

relativistic quantum theory *See* QUANTUM THEORY; QUANTUM FIELD THEORY.

relativistic runaway theory A theory of the origin of lightning in which it is proposed that lightning is initiated by a cosmic ray hitting a molecule in a cloud with an electric field. This releases an electron into the cloud, where it is accelerated in the field. The fast-moving electron then ionizes other atoms and molecules and there is a chain reaction producing many rapidly moving electrons. This theory explains how lightning can occur in spite of the electric field of the cloud being insufficient to cause breakdown ionization in air.

relativistic speed A speed that is sufficiently large to make the mass of a body significantly greater than its *rest mass. It is usually expressed as a proportion of the speed of light. *See* RELATIVITY; RELATIVISTIC MASS.

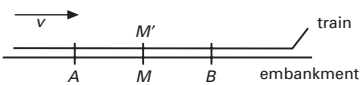
relativity Two widely accepted theories

proposed by Albert *Einstein to account for departures from Newtonian mechanics. The special theory, of 1905, refers to non-accelerated frames of reference, while the general theory, of 1915, extends to accelerated systems.

The special theory. For Galileo and Newton, all uniformly moving frames of reference (Galilean frames) are equivalent for describing the dynamics of moving bodies. There is no experiment in dynamics that can distinguish between a stationary laboratory and a laboratory that is moving at uniform velocity. Einstein's special theory of relativity takes this notion of equivalent frames one step further: he required all physical phenomena, not only those of dynamics, to be independent of the uniform motion of the laboratory.

When Einstein published his special theory, he realized that it could explain the apparent lack of experimental evidence for an ether, which was supposed to be the medium required for the propagation of electromagnetic waves (*see* MICHELSON–MORLEY EXPERIMENT). Einstein recognized that the existence of an ether would render invalid any equivalent relativity principle for electromagnetic phenomena; i.e. uniform movement of the laboratory through the ether would lead to measurable differences in the propagation of electromagnetic waves *in vacuo*. Since no experimental evidence of the ether was forthcoming, Einstein was encouraged to continue his search for a relativity principle that encompassed all physical phenomena. Since light is a physical phenomenon, its propagation *in vacuo* could not be used to distinguish between uniformly moving frames of reference. Therefore in all such frames the measured speed of light *in vacuo* must be the same.

This conclusion has some important consequences for the nature of space and time. In his popular exposition of 1916, Einstein illustrated these consequences with thought experiments. In one such experiment, he invites the reader to imagine a very long train travelling along an embankment with a constant velocity v in a given direction (see diagram).



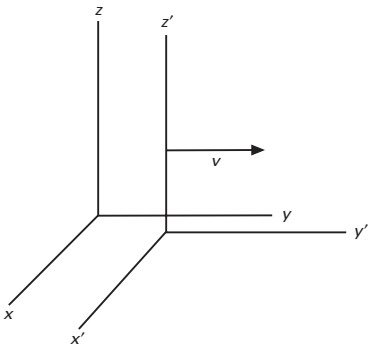
Relativity. Einstein's thought experiment.

Observers on the train use it as a rigid reference body, regarding all events with reference to the train. Einstein posed a simple question: Are two events, which are simultaneous relative to the railway embankment, also simultaneous relative to the observer on the train? For example, two lightning strokes strike the embankment at points *A* and *B* simultaneously with respect to the embankment, so that an observer at *M* (the mid-point of the line *AB*) will record no time lapse between them. However, the events *A* and *B* also correspond to positions *A* and *B* on the train. *M′* is the mid-point of the distance *AB* on the moving train. When the flashes occur, from the point of view of the embankment, *M′* coincides with *M*. However, *M* moves with speed v towards the right and therefore hastens towards the beam of light coming from *B*, while moving on ahead of the beam from *A*. The observer at *M′* would not agree with the observer at *M* on the simultaneity of the events *A* and *B* because the beam of light from *B* will be seen to be emitted before the beam of light at *A*.

At first sight there may seem to be a problem here. If the observer at *M′* is 'hastening towards the beam of light from *B*', is this not equivalent to saying that the beam of light is travelling towards *M′* at a combined speed of v + *c*, where *c* is the speed of light *in vacuo*?

The resolution of this problem is the basis of special relativity. According to Einstein, the moving observer at *M′* must measure the speed of light *in vacuo* to be *c*, since there can be no experiment that distinguishes the train's moving frame from any other Galilean frame. It is therefore the concept of time measurement that requires revision; that is, the time required for a particular event to occur with respect to the train cannot have the same duration as the same event when judged from the embankment.

This remarkable result also has implications for the measurement of spatial intervals. The measurement of a spatial interval requires the time coincidence of two points along a measuring rod. The relativity of simultaneity means that one cannot contend that an observer who traverses a distance *x* m per second in the train, traverses the same distance *x* m also with respect to the embankment in each second. In trying to include the law of propagation of light into a relativity principle, Einstein questioned the way in which measurements of space and time in different Galilean frames are compared. Place and time measurements in two



The frame (x', y', z') is moving uniformly with respect to (x, y, z) at a velocity v in the y direction.

Coordinates in the two frames are related as follows by the Lorentz transformations

$$y' = \frac{y - vt}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$t' = \frac{t - vy/c^2}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$x' = x$$
$$z' = z$$

Relativity. Lorentz transformations.

different Galilean frames must be related by a transformation preserving the relativity principle that every ray of light has a velocity of transmission c relative to observers in both frames.

Transformations that preserve the relativity principle are called *Lorentz transformations. The form of these looks complicated at first (see diagram). However, they arise from the simple requirement that there can be no experiment in dynamics or electromagnetism that will distinguish between two different Galilean frames of reference.

These transformations suggest that observers in the two frames will not agree on measurements of length made in the y-direction. Indeed, the duration of intervals of time cannot be agreed upon in the two frames. This is exactly what was suggested in Einstein's thought experiment on the train. Simple manipulations lead to the following formulae, which relate lengths and time intervals in the x', y', z' frame to their equivalent quantities in the x, y, z frame:

$$\Delta l = \Delta l' \, (1 - v^2/c^2)^{\frac{1}{2}}$$

and

$$\Delta t = \Delta t' \, (1 - v^2/c^2)^{-\frac{1}{2}},$$

where Δl and Δt are respectively intervals in space and time. Motion therefore leads to a length contraction of the x', y', z' lengths with respect to the x, y, z lengths. Similarly, the equation relating the time intervals in the two frames leads to a time dilation in the x', y', z' system compared to the x, y, z system. From these expressions it is clear that the velocity c plays the part of a limiting velocity, which can neither be reached nor exceeded by any material body.

The velocity c is often said to be the limiting velocity for the transfer of information in the universe. Faster-than-light signals violate *causality when taken to their logical conclusions. The universe, therefore, according to the special theory, of relativity, updates itself at the maximum speed of light c: any local changes in the properties within a region of space are not communicated to the rest of the universe instantaneously. Rather, the universe is updated through a wave of reality, which emanates at speed c from the region in which the change took place.

The general theory. In his special theory, Einstein updated the Galilean principle of relativity by including electromagnetic phenomena. Galileo, and later Newton, were well aware that no experiment in the dynamics of moving bodies could distinguish between frames of reference moving relative to each other at constant velocity (Galilean frames). If two Galilean frames move with respect to each other at uniform velocity, no experiment could determine which frame was in absolute motion and which frame was at absolute rest.

This is the basic principle of Einstein's special theory of relativity. However, Einstein was not content with the apparent absolute status conferred to accelerating frames by the behaviour of bodies within them. Einstein sought a general principle of relativity that would require all frames of reference, whatever their relative state of motion, to be equivalent for the formulation of the general laws of nature. In his popular exposition of 1916, Einstein explains this by describing the experiences of an observer

within a railway carriage that is decelerating. In his own words: "At all events it is clear that the Galilean law does not hold with respect to the non-uniformly moving carriage. Because of this, we feel compelled at the present juncture to grant a kind of absolute physical reality to non-uniform motion, in opposition to the general principle of relativity."

Once again it was one of Galileo's observations that provided the starting point for the formulation of Einstein's ideas. Galileo observed that bodies moving under the sole influence of a *gravitational field acquire an acceleration that does not depend upon the material or the physical state of the body. Einstein realized that this property of gravitational fields implied equivalence between gravity and accelerating frames of reference. This equivalence, which became the basis of his general theory of relativity, is well illustrated by one of Einstein's thought experiments. Imagine an elevator, so far removed from stars and other large masses that there is no appreciable gravitational field. An observer inside the elevator is equipped with the appropriate apparatus and uses the elevator as a reference frame. Initially, if the elevator is a Galilean frame, the observer would feel weightless with only inferences from decorations inside the elevator to distinguish between 'up' and 'down'. However, if a rope attached to the top of the elevator were to be pulled with a constant acceleration of 9.81 m s^{-2}, the observer would detect this acceleration as a force reaction on the floor of the elevator. The experiences of the observer in the elevator are equivalent to the experiences of an observer in an elevator in the earth's gravitational field of strength 9.81 N kg^{-1}. Moreover, the force reaction at the feet of the observer in the accelerating frame is due to the observer's inertial *mass (the mass that represents the reluctance of the observer's body to accelerate under the influence of a force).

An observer in the earth-bound elevator would feel the same force reaction at the floor of the elevator, but for this observer the force is due to the influence of the earth's gravitational field on the observer's gravitational mass. Guided by this example, Einstein realized that his extension of the principle of relativity to include accelerations implies the equality of inertial and gravitational mass, which had been established experimentally by Lóláand Eötvös (1848–1919) in 1888.

These considerations have significant implications for the nature of space and time under the influence of a gravitational field. Another of Einstein's thought experiments illustrates these implications. Imagine a Galilean frame of reference *K* from which an observer *A* takes measurements of a non-Galilean frame *K'*, which is a rotating disc inhabited by an observer *B*. *A* notes that *B* is in circular motion and experiences a centrifugal acceleration. This acceleration is produced by a force, which may be interpreted as an effect of *B*'s inertial mass. However, on the basis of the general principle of relativity, *B* may contend that he is actually at rest but under the influence of a radially directed gravitational field.

A comparison of time-measuring devices placed at the centre and edge of the rotating disc would show a remarkable result. For although the devices would both be at rest with respect to *K'*, the motion of the disc with respect to *K* would lead to a *time dilation at the edge with respect to measured time at the centre. It follows that the clock at the disc's periphery runs at a permanently slower rate than that at the centre, i.e. as observed from *K*. The same effect would be noted by an observer who is sitting next to the clock at the centre of the disc. Thus, on the disc, or indeed in any gravitational field, a timing device will run at different rates depending on where it is situated.

The measurement of spatial intervals on the rotating disc will also incur a similar lack of definition. Standard measuring rods placed tangentially around the circumference *C* of the disc will all be contracted in length due to relativistic length contraction with respect to *K*. However, measuring rods will not experience shortening in length, as judged from *K*, if they are applied across a diameter *D*. Dividing the circumference by the diameter would produce a surprising result from *K'*s point of view. Normally such a quotient would have the value $\pi = 3.14159\ldots$, but in this situation the quotient is larger. Euclidean geometry does not seem to hold in an accelerating frame, or indeed by the principle of relativity, within a gravitational field. Spaces in which the propositions of Euclid are not valid are sometimes called curved spaces. For example, the sum of the internal angles of a triangle drawn on a flat sheet of paper will be 180°; however, a triangle drawn on the curved surface of a sphere will not follow this Euclidean rule.

Einstein fully expected to see this effect in

gravitational fields, such was his belief in the general principle of relativity. In fact, it was the effect gravitational fields have on the propagation of light that was heralded as the major verification of his general relativity. Einstein realized that rays of light would be perceived as curving in an accelerating frame. This led him to conclude that, in general, rays of light are propagated curvilinearly in gravitational fields. By means of photographs taken of stars during the solar eclipse of 29 May 1919, the existence of the deflection of starlight around the sun's mass was confirmed.

The mathematics required to describe the curvature of space in the presence of gravitational fields existed before Einstein had need for it, but it was essentially rediscovered by Einstein to solve his general relativistic problems. In general relativity, material bodies follow lines of shortest distance, called **geodesics**. The line formed by stretching an elastic band over a curved surface would be a geodesic on the curved surface. Light follows geodesics called **null-geodesics**. The motions of material bodies are therefore determined by the curvature of the space in the region through which they pass. However, it is the mass of the bodies that causes the curvature of the space in the first place, which demonstrates the elegant self-consistency of Einstein's general theory.

relaxation oscillator *See* OSCILLATOR.

relay An electrical or electronic device in which a variation in the current in one circuit controls the current in a second circuit. These devices are used in an enormous number of different applications in which electrical control is required. The simplest is the electromechanical relay in which the first circuit energizes an electromagnet, which operates a switch in a second circuit. The *thyratron gas-filled relay found many uses in the past but has now been largely replaced by the *thyristor solid-state relay.

releaser *See* SIGN STIMULUS.

releasing hormone (releasing factor) A hormone that is produced by the hypothalamus and stimulates the release of a hormone from the anterior *pituitary gland into the bloodstream. Each hormone has a specific releasing hormone; for example, thyrotrophin-releasing hormone stimulates the release of *thyroid-stimulating hormone.

reluctance Symbol *R*. The ratio of the magnetomotive force to the total magnetic flux in a magnetic circuit or component. It is measured in henries.

reluctivity The reciprocal of magnetic *permeability.

rem *See* RADIATION UNITS.

remanence (retentivity) The magnetic flux density remaining in a ferromagnetic substance when the saturating field is reduced to zero. *See* HYSTERESIS.

remote sensing The gathering and recording of information concerning the earth's surface by techniques that do not involve actual contact with the object or area under study. These techniques include photography (e.g. aerial photography), multispectral imagery, infrared imagery, and radar. Remote sensing is generally carried out from aircraft and, increasingly, satellites. The techniques are used, for example, in cartography (map making).

renal Of or relating to the *kidney. For example, the **renal artery** and **renal vein** convey blood towards and away from the kidney, respectively.

renal capsule *See* BOWMAN'S CAPSULE.

renewable energy sources Sources of energy that do not use up the earth's finite mineral resources. **Nonrenewable energy sources** are *fossil fuels and fission fuels (*see* NUCLEAR FISSION). Various renewable energy sources are being used or investigated. *See* GEOTHERMAL ENERGY; HYDROELECTRIC POWER; NUCLEAR FUSION; SOLAR ENERGY; TIDES; WIND POWER; WAVE POWER.

renin A proteolytic enzyme (*see* PROTEASE) that is involved in the formation of the hormone *angiotensin, which raises blood pressure. Renin is secreted into the blood by cells of the kidney glomeruli under the control of the sympathetic nervous system; its release also occurs in response to a fall in blood-sodium levels and to falling blood pressure. Renin catalyses cleavage of circulating α_2-globulin to produce angiotensin I, precursor of the active hormone.

rennin (chymosin) An enzyme secreted by cells lining the stomach in mammals that is responsible for clotting milk. It acts on a soluble milk protein (**caseinogen**), which it converts to the insoluble form *casein. This ensures that milk remains in the stomach

long enough to be acted on by protein-digesting enzymes.

renormalization A procedure used in relativistic *quantum field theory to deal with the fact that in *perturbation theory calculations give rise to infinities beyond the first term. Renormalization was first used in *quantum electrodynamics, where the infinities were removed by taking the observed mass and charge of the electron as 'renormalized' parameters rather than the 'bare' mass and charge.

Theories for which finite results for all perturbation-theory calculations exist, by taking a finite number of parameters from experiment and using renormalization, are called **renormalizable**. Only certain types of quantum field theories are renormalizable. Theories that need an infinite number of parameters are said to be **nonrenormalizable** and are regarded as incomplete physical theories. The *gauge theories that describe the strong, weak, and electromagnetic interactions are renormalizable. The quantum theory of gravitational interactions is a nonrenormalizable theory, which perhaps indicates that gravity needs to be unified with other fundamental interactions before one can have a consistent quantum theory of gravity. Renormalization theory has been expressed in terms of noncommutative geometry.

renormalization group A technique used to understand systems in which many length-scales are involved. Such systems include phase transitions, turbulence, polymers, many-electron systems, and the localization of electrons in disordered systems. The renormalization group has its origin in *quantum field theory, in which it is used to calculate how *coupling constants change with energy. The way in which this change with energy takes place involves a *group and the procedure of *renormalization.

repetitive DNA DNA whose base sequence is repeated many times throughout the genome of an organism. It is common in eukaryotes, accounting for about half of the total DNA in mammals, for example, and can be divided into various types. Some serves a useful purpose, but a significant proportion is of uncertain function, and may be 'junk', or *selfish DNA. One important type consists of multiple copies of particular genes or gene sequences, which may be duplicates of genes encoding histones or ribosomal RNAs. **Satellite DNA** – repeats of short DNA sequences (typically less than 10 bp) flanking the centromeres of each chromosome and stretching for hundreds of kilobases along either arm of the chromosome – and telomeric DNA (*see* TELOMERE) are important for maintaining chromosome structure. Other distinct types of repetitive DNA dispersed throughout the genome, both in noncoding introns within genes and between genes, include **minisatellite DNA** (variable number tandem repeats) – sequences of 15–100 bp repeated hundreds or thousands of times – and **microsatellite DNA**, repeats of shorter sequences (2–6 bp). Both these types are of value as *molecular markers in DNA fingerprinting.

replacing bone *See* CARTILAGE BONE.

replicon A DNA sequence that is replicated as a unit from a single initiation site (origin of replication). The genome of a bacterium or a virus comprises a single replicon; eukaryotes contain a number of replicons on each chromosome.

repolarization The restoration of the *resting potential in neurons or muscle fibres following the passage of a nerve impulse. Repolarization is brought about by diffusion of potassium ions out of the neuron and by active elimination of sodium ions (*see* SODIUM PUMP).

Reppe processes A set of related industrial reactions of acetylene to produce vinyl compounds, such as

$$HC{\equiv}CH + ROH \rightarrow H_2C{=}CHR$$

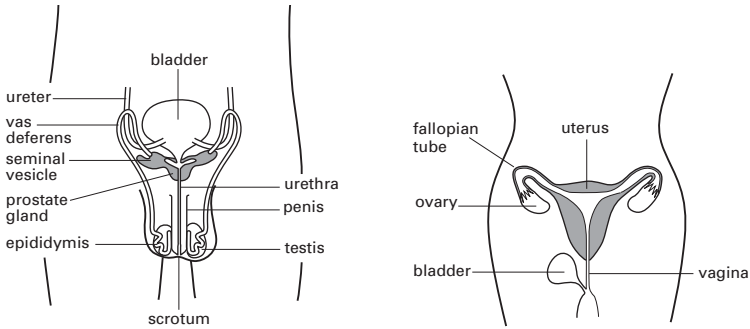
$$HC{\equiv}CH + RCN \rightarrow H_2C{=}CR(CN)$$

They take place at high pressure using metal acelylide catalysts. The processes are named after the German chemist Walter Reppe (1892–1969), who pioneered techniques for the safe industrial use of acetylene.

repressor A protein that can prevent the expression of a gene. *See* OPERON.

reproduction The production of new individuals more or less similar in form to the parent organisms. This may be achieved by a number of means (*see* SEXUAL REPRODUCTION; ASEXUAL REPRODUCTION) and serves to perpetuate or increase a species.

reproductive system The organs that are involved in the process of *sexual reproduction in an organism. The reproductive



Reproductive system. The human male (left) and female (right) systems.

system of a flowering plant is found in the *flower and consists of the stamens (male organs) and carpels (female organs). In mammals the reproductive system consists of the testes, epididymis, sperm duct, and penis in the male and the ovaries, fallopian tubes, and uterus in the female.

Reptilia The class that contains the first entirely terrestrial vertebrates, which can live in dry terrestrial habitats as their skin is covered by a layer of horny scales, preventing water loss. They breathe atmospheric oxygen by means of lungs assisted by respiratory movements principally involving the ribs (there is no diaphragm). Reptiles are cold-blooded (*see* POIKILOTHERMY) but behavioural patterns make it possible for them to maintain a fairly even body temperature throughout the day. Fertilization is internal and the majority of reptiles lay eggs on land. These eggs have a porous shell to provide protection from desiccation and allow gas exchange. In some reptiles the eggs are retained within the body of the mother until the young are ready to hatch, thereby greatly reducing juvenile mortality (*see* OVOVIVIPARITY).

The class includes the modern crocodiles, lizards and snakes (*see* SQUAMATA), and tortoises and turtles, as well as many extinct forms, such as the *dinosaurs and *Pterosauria.

SEE WEB LINKS

- This Amniota page from the Tree of Life Project shows the phylogenetic relationships of reptile groups, birds, and mammals

residual volume The amount of air remaining in the lungs after maximum expiration, which cannot be expelled from the lungs voluntarily. An average human has a residual volume of about 1 litre. *See also* VITAL CAPACITY.

resin A synthetic or naturally occurring *polymer. Synthetic resins are used in making *plastics. Natural resins are acidic chemicals secreted by many trees (especially conifers) into ducts or canals. They are found either as brittle glassy substances or dissolved in essential oils. Their functions are probably similar to those of gums and mucilages, i.e. protective.

resistance **1.** (in physics) Symbol *R*. The ratio of the potential difference across an electrical component to the current passing through it. It is thus a measure of the component's opposition to the flow of electric charge. In general, the resistance of a metallic conductor increases with temperature, whereas the resistance of a *semiconductor decreases with temperature. **2.** (in microbiology) The degree to which pathogenic microorganisms remain unaffected by antibiotics and other drugs. Genes for antibiotic resistance are often carried on *plasmids or *transposons, which can spread across species barriers. **3.** (in ecology) **a.** The degree to which a *pest can withstand the effects of a pesticide. It depends on the selection and spread within a pest population of genes that confer the ability to destroy, or minimize the effects of, a pesticide. **b.** *See* ENVIRONMENTAL RESISTANCE. **4.** (in immunology) The degree of *immunity to infection that an animal possesses.

resistance thermometer (resistance pyrometer) A *thermometer that relies on the

increase of electrical resistance of a metal wire with rising temperature, according to the approximate relationship

$R = R_0(1 + aT + bT^2)$,

where R is the resistance of the wire at temperature T and R_0 is the resistance of the wire at a reference temperature, usually 0°C; a and b are constants characteristic of the metal of the wire. The metal most frequently used is platinum and the platinum resistance coil is usually incorporated into one arm of a *Wheatstone bridge. The effect of the temperature change on the leads carrying current to the platinum coil is compensated by including a pair of dummy leads within the casing carrying the coil. *See also* THERMISTOR.

resistivity Symbol ρ. A measure of a material's ability to oppose the flow of an electric current. It is given by RA/l, where R is the resistance of a uniform specimen of the material, having a length l and a cross-sectional area A. It is usually given at 0°C or 20°C and is measured in ohm metres. It was formerly known as **specific resistance**.

SEE WEB LINKS

- Values of resistivity for a range of materials at the NPL website

resistor A component in an electrical or electronic circuit that is present because of its electrical resistance. For electronic purposes many resistors are either wire-wound or consist of carbon particles in a ceramic binder. The ceramic coating carries a number or colour code indicating the value of the resistance. Some resistors can be varied manually by means of a sliding contact; others are markedly dependent on temperature or illumination.

resolution **1.** (in chemistry) The process of separating a racemic mixture into its optically active constituents. In some cases the crystals of the two forms have a different appearance, and the separation can be done by hand. In general, however, physical methods (distillation, crystallization, etc.) cannot be used because the optical isomers have identical physical properties. The most common technique is to react the mixture with a compound that is itself optically active, and then separate the two. For instance, a racemic mixture of (–)-A and (+)-A reacted with (–)-B, gives two compounds AB that are not optical isomers but diastereoisomers and can be separated and reconverted into the pure (–)-A and (+)-A. Biological techniques using bacteria that convert one form but not the other can also be used. **2.** (in mathematics) The separation of a vector quantity into two components, which are usually at right angles to each other. Thus, a force F acting on a body in a vertical plane at an angle θ to the horizontal can be resolved into a horizontal component $F\cos\theta$ and a vertical component $F\sin\theta$, both in the same plane as the original force. **3.** (in optics) *See* RESOLVING POWER.

resolving power A measure of the ability of an optical instrument to form separable images of close objects or to separate close wavelengths of radiation. The **chromatic resolving power** for any spectroscopic instrument is equal to $\lambda/\delta\lambda$, where $\delta\lambda$ is the difference in wavelength of two equally strong spectral lines that can barely be separated by the instrument and λ is the average wavelength of these two lines. For a telescope forming images of stars the **angular resolving power** is the smallest angular separation of the images; the **linear resolving power** is the linear separation of the images in the focal plane. In a telescope forming images of two stars, as a result of diffraction by the lens aperture each image consists of a bright central blob surrounded by light and dark rings. According to the **Rayleigh criterion** for resolution, the central ring of one image should fall on the first dark ring of the other. The angular resolving power in radians is then $1.22\lambda/d$, where d is the diameter of the objective lens in centimetres and λ is the wavelength of the light (usually taken as 560 nanometres). For microscopes, the resolving power is usually taken as the minimum distance between two points that can be separated. In both cases, the smaller the resolving power, the better the resolution; to avoid this apparent paradox the resolving power is now sometimes taken as the reciprocals of the quantities stated above.

resonance **1.** (in physics) An oscillation of a system at its natural frequency of vibration, as determined by the physical parameters of the system. It has the characteristic that large amplitude vibrations will ultimately result from low-power driving of the system. Resonance can occur in atoms and molecules, mechanical systems, and electrical circuits (*see* RESONANT CIRCUIT; RESONANT CAVITY). **2.** (in particle physics) A very short-lived *elementary particle that can be regarded as an excited state of a more stable

particle. Resonances decay by the strong interaction (*see* FUNDAMENTAL INTERACTIONS) in 10^{-24} second. **3.** (in chemistry) The representation of the structure of a molecule by two or more conventional formulae. For example, the formula of methanal can be represented by a covalent structure $H_2C{=}O$, in which there is a double bond in the carbonyl group. It is known that in such compounds the oxygen has some negative charge and the carbon some positive charge. The true bonding in the molecule is somewhere between $H_2C{=}O$ and the ionic compound $H_2C^+O^-$. It is said to be a **resonance hybrid** of the two, indicated by

$$H_2C{=}O \leftrightarrow H_2C^+O^-$$

The two possible structures are called **canonical forms**, and they need not contribute equally to the actual form. The double-headed arrow does not imply that the two forms are in equilibrium.

resonant cavity (cavity resonator) A closed space within a conductor in which an electromagnetic field can be made to oscillate at frequencies above those at which a *resonant circuit will operate. The resonant frequency of the oscillation will depend on the dimensions and the shape of the cavity. The device is used to produce microwaves (*see* KLYSTRON; MAGNETRON).

resonant circuit A reactive circuit (*see* REACTANCE) so arranged that it is capable of *resonance. In a **series resonant circuit** a resistor, inductor, and capacitor are arranged in series. Resonance occurs when the *impedance (Z) is a minimum and the current amplitude therefore a maximum. In a **parallel resonant circuit** the inductance and capacitance are in parallel and resonance (with minimal current amplitude) occurs at maximum impedance. The frequency at which resonance occurs is called the **resonant frequency**. In a series resonant circuit

$$Z = R + \mathrm{i}[\omega L - 1/\omega C],$$

where $\omega = 2\pi f$ and f is the frequency, R is the resistance, L is the inductance, and C is the capacitance. At resonance, Z is a minimum and $\omega L = 1/\omega C$, i.e. the circuit behaves as if it is purely resistive. In the parallel circuit, resonance occurs when $R^2 + \omega^2 L^2 = L/C$, which in most cases also approximates to $\omega L = 1/\omega C$. Resonant circuits are widely used in *radio to select one signal frequency in preference to others.

resonating valence bond theory An extension of *valence bond theory to solids in which there is quantum-mechanical *resonance between different structures throughout the solid. Attempts have been made to describe high-temperature *superconductivity in terms of resonating valence bond theory.

respiration The metabolic process in animals and plants in which organic substances are broken down to simpler products with the release of energy, which is incorporated into special energy-carrying molecules (*see* ATP) and subsequently used for other metabolic processes. In most plants and animals respiration requires oxygen, and carbon dioxide is an end product. The exchange of oxygen and carbon dioxide between the body tissues and the environment is called **external respiration** (*see* VENTILATION). In many animals the exchange of gases takes place at *respiratory organs (e.g. *lungs in air-breathing vertebrates) and is assisted by *respiratory movements (e.g. breathing). In plants oxygen enters through pores on the plant surface and diffuses through the tissues via intercellular spaces or dissolved in tissue fluids.

Respiration at the cellular level is known as **internal** (or **tissue**) **respiration** and can be divided into two stages. In the first, *glycolysis, glucose is broken down to pyruvate. This does not require oxygen and is a form of *anaerobic respiration. In the second stage, the *Krebs cycle, pyruvate is broken down by a cyclic series of reactions to carbon dioxide and water. This is the main energy-yielding stage and requires oxygen. The processes of glycolysis and the Krebs cycle are common to all plants and animals that respire aerobically (*see* AEROBIC RESPIRATION).

SEE WEB LINKS

- Overview of cellular respiration, with animation and illustrations; from About.com.

respiratory chain *See* ELECTRON TRANSPORT CHAIN.

respiratory movement The muscular movement that enables the passage of air to and from the lungs or other *respiratory organs of an animal. The mechanism of the movement varies with the species. In insects abdominal muscles relax and contract rhythmically to encourage the flow of air through the *tracheae. In amphibians air is drawn into the lungs by a pumping action of the muscles in the floor of the mouth. **Breathing** in mammals involves the muscle of the *dia-

phragm and the *intercostal muscles between the ribs. Contraction of these muscles lowers the diaphragm and raises the ribs, so that the lungs expand and air is drawn in (*see* INSPIRATION). Relaxation has the opposite effect and forces air out during *expiration.

respiratory organ Any animal organ across which exchange of carbon dioxide and oxygen takes place. The surface membranes of such organs are always moist, thin, and well supplied with blood. Examples are the *lungs of air-breathing vertebrates, the *gills of fish, and the *tracheae of insects.

respiratory pigment A coloured compound that is capable of reversibly binding with oxygen at high oxygen concentrations and releasing it at low oxygen concentrations. Such pigments are present in the blood, transporting oxygen within the circulatory system from the *respiratory organs to the tissues of the body. In vertebrates the respiratory pigment is *haemoglobin, contained in the erythrocytes (red blood cells). *See also* HAEMOCYANIN.

respiratory quotient (RQ) The ratio of the volume of carbon dioxide produced by an organism during respiration to the volume of oxygen consumed. The RQ is usually about 0.8.

respirometer Any device that measures an organism's oxygen uptake. Simple respirometers consist of a chamber (in which the organism is placed) connected to a *manometer. Carbon dioxide is chemically removed from the chamber so that only oxygen uptake is measured. Human oxygen consumption is generally measured by a device known as a **spirometer**, which can also be used to measure depth and frequency of breathing.

response The physiological, muscular, or behavioural activity that can be elicited by a *stimulus.

rest energy The *rest mass of a body expressed in energy terms according to the relationship $E_0 = m_0c^2$, where m_0 is the rest mass of the body and c is the speed of light.

resting potential The difference in electrical potential that exists across the membrane of a nerve cell that is not in the process of transmitting a nerve impulse. The resting potential is maintained by means of the *sodium pump. *Compare* ACTION POTENTIAL.

restitution coefficient Symbol *e*. A measure of the elasticity of colliding bodies. For two spheres moving in the same straight line,

$$e = (v_2 - v_1)/(u_1 - u_2),$$

where u_1 and u_2 are the velocities of bodies 1 and 2 before collision ($u_1 > u_2$) and v_1 and v_2 are the velocities of 1 and 2 after impact ($v_2 > v_1$). If the collision is perfectly elastic $e = 1$ and the kinetic energy is conserved; for an inelastic collision $e < 1$.

rest mass The mass of a body at rest when measured by an observer who is at rest in the same frame of reference. *Compare* RELATIVISTIC MASS.

restriction enzyme (restriction endonuclease) A type of enzyme that can cleave molecules of foreign DNA at a particular site. Restriction enzymes are produced by many bacteria and protect the cell by cleaving (and therefore destroying) the DNA of invading viruses. The bacterial cell is protected from attack by its own restriction enzymes by modifying the bases of its DNA during replication. Restriction enzymes are widely used in the techniques of genetic engineering (*see* DNA PROFILING; DNA LIBRARY; DNA SEQUENCING; GENE CLONING; RESTRICTION MAPPING).

restriction fragment length polymorphism (RFLP) The occurrence of different cleavage sites for *restriction enzymes in the DNA of different individuals of the same species. Cleavage of DNA from different individuals with restriction enzymes thus produces differing sets of restriction fragments. The deletion of existing restriction sites or the creation of new ones is the result of random base changes in the noncoding stretches of DNA (*introns) between genes. RFLPs have provided geneticists with a powerful set of genetic markers for mapping the genome (*see* RESTRICTION MAPPING) and for identifying particular genes (*see* GENE TRACKING).

restriction mapping A technique for determining the sites at which a length of DNA (e.g. from a chromosome) is cleaved by *restriction enzymes. By cleaving the DNA with various such enzymes, both individually and in combination, and analysing the resultant number and size of fragments by electrophoresis, a **restriction map**, indicating the order of restriction sites in the original DNA, can be deduced (*see also* LINKAGE MAP). Gene deletions or rearrangements that alter

the restriction sites can be detected as changes in the pattern of fragments obtained. This may be used, for instance, to diagnose certain genetic abnormalities in the fetus. The fragments are separated by gel electrophoresis and identified using specific *gene probes, as in the *Southern blotting technique. The absence of a certain fragment in a fetal DNA digest can be diagnostic of a pathological change in the fetal gene containing the corresponding restriction site.

resultant A *vector quantity that has the same effect as two or more other vector quantities of the same kind. *See* PARALLELOGRAM OF VECTORS.

retardation (deceleration) The rate of reduction of speed, velocity, or rate of change.

retardation plate A transparent plate of a birefringent material, such as quartz, cut parallel to the optic axis. Light falling on the plate at 90° to the optic axis is split into an ordinary ray and an extraordinary ray (*see* DOUBLE REFRACTION), which travel through the plate at different speeds. By cutting the plate to different thicknesses a specific phase difference can be introduced between the transmitted rays. In the **half-wave plate** a phase difference of π radians, equivalent to a path difference of half a wavelength, is introduced. In the **quarter-wave plate** the waves are out of step by one quarter of a wavelength.

reticular formation *See* BRAINSTEM.

reticulum The first of four chambers that form the stomach of ruminants. *See* RUMINANTIA.

retina The light-sensitive membrane that lines the interior of the eye. The retina consists of two layers. The inner layer contains nerve cells, blood vessels, and two types of light-sensitive cells (*rods and *cones). The outer layer is pigmented, which prevents the back reflection of light and consequent decrease in visual acuity. Light passing through the lens stimulates individual rods and cones, which generates nerve impulses that are transmitted through the optic nerve to the brain, where the visual image is formed.

retinal *See* RHODOPSIN; VITAMIN A.

retinol *See* VITAMIN A.

retort **1.** A laboratory apparatus consisting of a glass bulb with a long neck. **2.** A vessel used for reaction or distillation in industrial chemical processes.

retrograde motion **1.** The apparent motion of a planet from east to west as seen from the earth against the background of the stars. **2.** The clockwise rotation of a planet, as seen from its north pole. *Compare* DIRECT MOTION.

retrorocket A small rocket motor that produces thrust in the opposite direction to a *rocket's main motor or motors in order to decelerate it.

retrotransposon A type of *transposon found in the DNA of various organisms, including yeast, *Drosophila*, and mammals, that forms copies of itself using a mechanism similar to that of retroviruses. It undergoes transcription to RNA, then creates a DNA copy of the transcript with the aid of the enzyme *reverse transcriptase. This DNA copy can then reintegrate into the cell's genome.

retrovirus An RNA-containing virus that converts its RNA into DNA by means of the enzyme *reverse transcriptase; this enables it to become integrated into its host's DNA. Some retroviruses can cause cancer in animals: they contain *oncogenes, which are activated when the virus enters its host cell and starts to replicate. Retroviruses are useful as *vectors for inserting genetic material into eukaryotic cells. The best-known retrovirus is *HIV, responsible for AIDS in humans. *See also* PROVIRUS.

reverberation time The time taken for the energy density of a sound to fall to the threshold of audibility from a value 10^6 times as great; i.e. a fall of 60 decibels. It is an important characteristic of an auditorium. The optimum value is proportional to the linear dimensions of the auditorium.

reverberatory furnace A metallurgical furnace in which the charge to be heated is kept separate from the fuel. It consists of a shallow hearth on which the charge is heated by flames that pass over it and by radiation reflected onto it from a low roof.

reverse genetics Any approach to genetic investigation that aims to find the function for some known protein or gene. It contrasts with the more traditional *forward genetics approach. For example, analysis of gene sequences reveals open reading frames, which are the hallmarks of functional genes

(*see* READING FRAME). Reverse genetics methods can be used to discover the function of such genes, which can be cloned, subjected to mutation, and then reinserted into the organism (e.g. a bacterium or yeast cell) to see what effect the mutations have on function. A similar approach can be taken starting with a protein of unknown function. The amino-acid sequence can be back-translated into genetic code, a DNA probe constructed for part of the DNA sequence, and the relevant gene selected from a *DNA library of the organism.

reverse osmosis A method of obtaining pure water from water containing a salt, as in *desalination. Pure water and the salt water are separated by a semipermeable membrane and the pressure of the salt water is raised above the osmotic pressure, causing water from the brine to pass through the membrane into the pure water. This process requires a pressure of some 25 atmospheres, which makes it difficult to apply on a large scale. The process is used for the purification of drinking water.

reverse transcriptase An enzyme, occurring in *retroviruses, that catalyses the formation of double-stranded DNA using the single RNA strand of the viral genome as template. This enables the viral genome to be inserted into the host's DNA and replicated by the host. Reverse transcriptase is thus an RNA-directed DNA *polymerase. The enzyme is used in genetic engineering for producing *complementary DNA from messenger RNA.

reversible process Any process in which the variables that define the state of the system can be made to change in such a way that they pass through the same values in the reverse order when the process is reversed. It is also a condition of a reversible process that any exchanges of energy, work, or matter with the surroundings should be reversed in direction and order when the process is reversed. Any process that does not comply with these conditions when it is reversed is said to be an **irreversible process**. All natural processes are irreversible, although some processes can be made to approach closely to a reversible process.

Reynolds number Symbol *Re*. A dimensionless number used in fluid dynamics to determine the type of flow of a fluid through a pipe, to design prototypes from small-scale models, etc. It is the ratio $v\rho l/\eta$, where v is the flow velocity, ρ is the fluid density, l is a characteristic linear dimension, such as the diameter of a pipe, and η is the fluid viscosity. In a smooth straight uniform pipe, laminar flow usually occurs if $Re < 2000$ and turbulent flow is established if $Re > 3000$. It is named after Osborne Reynolds (1842–1912).

RFLP *See* RESTRICTION FRAGMENT LENGTH POLYMORPHISM.

R_F value (in chromatography) The distance travelled by a given component divided by the distance travelled by the solvent front. For a given system at a known temperature, it is a characteristic of the component and can be used to identify components.

Rh *See* RHESUS FACTOR.

rhachis *See* RACHIS.

rhe A unit of fluidity equal to the reciprocal of the *poise.

rhenium Symbol Re. A silvery-white metallic *transition element; a.n. 75; r.a.m. 186.2; r.d. 20.53; m.p. 3180°C; b.p. 5627 (estimated)°C. The element is obtained as a by-product in refining molybdenum, and is used in certain alloys (e.g. rhenium–molybdenum alloys are superconducting). It forms a number of complexes with oxidation states in the range 1–7. It was discovered by Walter Noddack (1893–1960) and Ida Tacke in 1925.

SEE WEB LINKS

- Information from the WebElements site

rheology The study of the deformation and flow of matter.

rheopexy The process by which certain thixotropic substances set more rapidly when they are stirred, shaken, or tapped. Gypsum in water is such a **rheopectic substance**.

rheostat A variable *resistor, the value of which can be changed without interrupting the current flow. In the common wire-wound rheostat, a sliding contact moves along the length of the coil of wire.

rhesus factor (Rh factor) An *antigen whose presence or absence on the surface of red blood cells forms the basis of the rhesus *blood group system. (The factor was first recognized in rhesus monkeys.) Most people possess the Rh factor, i.e. they are rhesus positive (Rh+). People who lack the factor are Rh–. If Rh+ blood is given to an Rh– patient,

the latter develops anti-Rh antibodies. Subsequent transfusion of Rh+ blood results in *agglutination, with serious consequences. Similarly, an Rh– pregnant woman carrying an Rh+ fetus may develop anti-Rh antibodies in her blood; these will react with the blood of a subsequent Rh+ fetus, causing anaemia in the newborn baby.

rhizoid One of a group of delicate and often colourless hairlike outgrowths found in certain algae and the gametophyte generation of bryophytes and ferns. They anchor the plant to the substrate and absorb water and mineral salts.

rhizome A horizontal underground stem. It enables the plant to survive from one growing season to the next and in some species it also serves to propagate the plant vegetatively. It may be thin and wiry, as in couch grass, or fleshy and swollen, as in *Iris*. Compact upright underground stems, as in rhubarb, strawberry, and primrose, are often called **rootstocks**.

rhizosphere The zone immediately surrounding the actively growing region of a plant root. Typically 1–2 mm thick, it consists of a *biofilm of water and soluble substances derived from the plant, soil constituents, and a community of fungi, bacteria, and other microorganisms that interact with each other and with the plant. The rhizosphere has a profound influence on the growth and survival of the plant, notably in helping it to absorb nutrients from the soil and inhibiting root pathogens, and on soil composition and structure.

rhodium Symbol Rh. A silvery-white metallic *transition element; a.n. 45; r.a.m. 102.9; r.d. 12.4; m.p. 1966°C; b.p. 3727°C. It occurs with platinum and is used in certain platinum alloys (e.g. for thermocouples) and in plating jewellery and optical reflectors. Chemically, it is not attacked by acids (dissolves only slowly in aqua regia) and reacts with nonmetals (e.g. oxygen and chlorine) at red heat. Its main oxidation state is +3 although it also forms complexes in the +4 state. The element was discovered in 1803 by William Wollaston (1766–1828).

SEE WEB LINKS

- Information from the WebElements site

Rhodophyta (red algae) A phylum of *algae that are often pink or red in colour due to the presence of the pigments phycocyanin and phycoerythrin. Members of the Rhodophyta may be unicellular or multicellular; the latter form branched flattened thalli or filaments. They are commonly found along the coasts of tropical areas. Red algae are now regarded as members of the assemblage Archaeplastida (*see* PLANT).

rhodopsin (visual purple) The light-sensitive pigment found in the *rods of the vertebrate retina. It consists of a protein component, **opsin**, linked to a nonprotein part, **retinal** (a derivative of *vitamin A). Light falling on the rod is absorbed by the retinal, which changes its form and separates from the opsin component; this initiates the transmission of a nerve impulse to the brain. The great sensitivity of rhodopsin allows vision in dim light (night vision).

rhombencephalon *See* HINDBRAIN.

rhombus A parallelogram in which all the sides are of equal length.

rhumb line (loxodrome) (in navigation) A line of constant compass direction that cuts across all lines of longitude at the same angle. The rhumb line is not the shortest distance between two points unless the two points are on the same meridian or on the equator. On the Mercator map projection a rhumb line is represented by a straight line.

rhyolite An igneous rock, the volcanic equivalent of granite. It is usually glassy or cryptocrystalline and consists of quartz, feldspars, and mica or amphibole. It may contain larger crystals (phenocrysts) set in a much finer-grained matrix.

rhytidome *See* BARK.

rib One of a series of slender curved bones that form a cage to enclose, support, and protect the heart and lungs (*see* THORAX). Ribs occur in pairs, articulating with the *thoracic vertebrae of the spinal column at the back and (in reptiles, birds, and mammals) with the *sternum (breastbone) in front. Movements of the rib cage, controlled by **intercostal muscles** between the ribs, are important in breathing (*see* RESPIRATORY MOVEMENT).

riboflavin *See* VITAMIN B COMPLEX.

ribonuclease *See* RNASE.

ribonucleic acid *See* RNA.

ribonucleoprotein (RNP) Any complex of protein and RNA that forms during the synthesis of RNA in eukaryotes; the protein is in-

volved in the packaging and condensation of the RNA. Certain RNPs are restricted to the nucleus whereas others are found in both the nucleus and the cytoplasm. The most common RNP occurring in the nucleus is **heterogeneous nuclear RNP** (**hnRNP**), which consists of protein bound to the primary transcript of DNA (*see* TRANSCRIPTION). It may be associated with **small nuclear RNP** (**snRNP**), which is involved in the removal of intron sequences from the primary transcript to form messenger RNA, which eventually leaves the nucleus (*see* GENE SPLICING).

ribose A *monosaccharide, $C_5H_{10}O_5$, rarely occurring free in nature but important as a component of *RNA (ribonucleic acid). Its derivative **deoxyribose**, $C_5H_{10}O_4$, is equally important as a constituent of *DNA (deoxyribonucleic acid), which carries the genetic code in chromosomes.

ribosomal RNA *See* RIBOSOME; RNA.

ribosome A small spherical body within a living cell that is the site of *protein synthesis. Ribosomes consist of two subunits, one large and one small, each of which comprises a type of RNA (called **ribosomal RNA**) and protein. Usually there are many ribosomes in a cell, either attached to the *endoplasmic reticulum or free in the cytoplasm. During protein synthesis they are associated with messenger RNA as *polyribosomes in the process of *translation.

ribozyme (catalytic RNA) Any RNA molecule that can catalyse changes to its own molecular structure. Self-splicing introns (*see* GENE SPLICING) are examples of ribozymes.

ribulose A ketopentose sugar (*see* MONOSACCHARIDE), $C_5H_{11}O_5$, that is involved in carbon dioxide fixation in photosynthesis as a component of *ribulose bisphosphate.

ribulose bisphosphate (RuBP) A five-carbon sugar that is combined with carbon dioxide to form two three-carbon intermediates in the first stage of the light-independent reactions of *photosynthesis (*see* CALVIN CYCLE). The enzyme that mediates the carboxylation of ribulose bisphosphate is **ribulose bisphosphate carboxylase/oxygenase** (**rubisco**).

Richardson equation (Richardson–Dushman equation) *See* THERMIONIC EMISSION.

Richter scale A logarithmic scale devised in 1935 by Charles Richter (1900–85) to compare the magnitude of earthquakes. The scale ranges from 0 to 10 and the Richter scale value is related to the logarithm of the amplitude of the ground motion divided by the period of the dominant wave, subject to certain corrections. On this scale a value of 2 can just be felt as a tremor and damage to buildings occurs for values in excess of 6. The largest shock recorded had a magnitude of 9.5.

ricin A highly toxic protein present in the castor oil plant (*Ricinus communis*), in particular in the seeds of the plant (castor beans). It is probably the most poisonous substance present in plants – the fatal dose is about 1 milligram per kilogram of body weight.

rickets A childhood condition caused by decalcification of bone, resulting in deformed bones. Rickets is associated with chronic deficiency of *vitamin D or calcium and with disorders that cause poor phosphate reabsorption from the kidney *nephrons.

rickettsia A very small spherical or rod-shaped Gram-negative bacterium belonging to the phylum Proteobacteria. Most rickettsias are obligate parasites, being unable to reproduce outside the cells of their hosts. Rickettsias can infect such arthropods as ticks, fleas, lice, and mites, through which they can be transmitted to vertebrates, including humans. The group includes the causal agents of trench fever, Rocky Mountain spotted fever, and forms of typhus.

rift valley A steep-sided depression that occurs in regions in which there is *plate tectonic activity. Upwelling of magma causes a part of a plate to dome up and stretch. Subsequently a pair of long normal faults form, and the valley collapses between them; it is in effect a large *graben. The valleys may be extremely large, e.g. the East African Rift Valley extends for more than 4000 km, with cliff-like edges 2–3 km tall.

right ascension A coordinate used with *declination for locating an object on the *celestial sphere; it is equivalent to longitude in the earth's *latitude and longitude system, except that its zero point is not a prime meridian. Right ascension is measured along the celestial equator. The 360° around the equator are divided into 24 hours (1 hour = 15°) with subdivisions into minutes and sec-

onds; the intersection of the ecliptic and the equator at the vernal equinox is taken as 0 hours. A celestial object's right ascension is defined as the angular distance from the vernal equinox eastward along the celestial equator to the **hour circle**, the perpendicular great circle passing through the object.

rigidity modulus *See* ELASTIC MODULUS.

ring A closed chain of atoms in a molecule. In compounds, such as naphthalene, in which two rings share a common side, the rings are **fused rings**. **Ring closures** are chemical reactions in which one part of a chain reacts with another to form a ring, as in the formation of *lactams and *lactones.

SEE WEB LINKS

- Information about IUPAC nomenclature of fused rings

Ringer's solution *See* PHYSIOLOGICAL SALINE.

R-isomer *See* ABSOLUTE CONFIGURATION.

ritualization An evolutionary process in which the form or context of an action is altered because it comes to play a role in social communication. For example, many *courtship and greeting ceremonies in animals include ritual food presentation (though the quantities of food may be negligible), derived from the action of feeding the young.

RME *See* BIOFUEL.

RMS value *See* ROOT-MEAN-SQUARE VALUE.

RNA (ribonucleic acid) A complex organic compound (a nucleic acid) in living cells that is concerned with *protein synthesis. In some viruses, RNA is also the hereditary material. Most RNA is synthesized in the nucleus and then distributed to various parts of the cytoplasm. An RNA molecule consists of a long chain of *nucleotides in which the sugar is *ribose and the bases are adenine, cytosine, guanine, and uracil (see illustration; *compare* DNA). **Messenger RNA** (**mRNA**) is responsible for carrying the *genetic code transcribed from DNA to specialized sites within the cell (known as *ribosomes), where the information is translated into protein composition (*see* TRANSCRIPTION; TRANSLATION). **Ribosomal RNA** (**rRNA**) is present in ribosomes; it is single-stranded but helical regions are formed by *base pairing within the strand. **Transfer RNA** (**tRNA**, **soluble RNA**, **sRNA**) is involved in the assembly of amino acids in a protein chain being synthesized at a ribosome. Each tRNA is specific for an amino acid and bears a triplet of bases complementary with a triplet on mRNA (*see* CODON). *See also* ANTISENSE RNA; RIBONUCLEOPROTEIN.

SEE WEB LINKS

- Animated account of the roles of RNA in protein synthesis; part of the 'DNA from the Beginning' website

RNAase *See* RNASE.

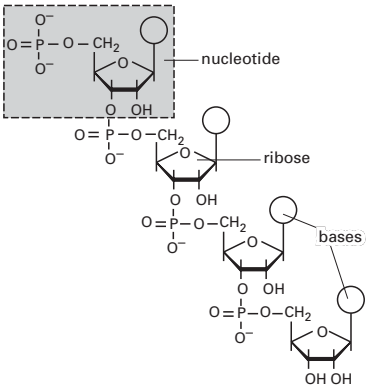
RNA interference (RNAi) The ability of double-stranded RNA to interfere with or suppress (silence) the expression of a gene with a corresponding base sequence. It involves a ribonuclease called **Dicer** cutting double-stranded RNA into fragments (21–22 nucleotides), one strand of which (the antisense strand) possesses a base sequence complementary to that of the target gene's mRNA; this strand is then incorporated into an assemblage of proteins, the **RNA-induced silencing complex** (**RISC**), which binds to the target mRNA and causes **gene silencing** by degrading the mRNA or preventing its translation into protein (*see* MICRORNA). RNAi is a regulating mechanism for an estimated 30% of all protein-coding genes in mammals. It also helps protect cells against certain viruses by targeting viral RNA, and it helps to silence potentially disruptive *transposons by destroying RNA copies arising from transposon replication.

RNA polymerase *See* POLYMERASE.

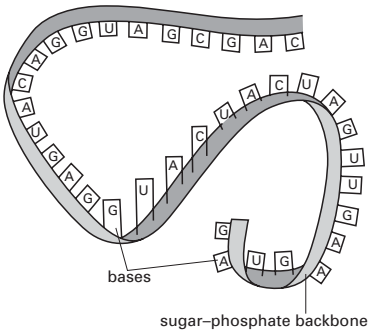
RNase (ribonuclease; **RNAase)** Any enzyme that catalyses the cleavage of nucleotides in RNA. Each RNase has a specificity for a different cleavage site. For example, RNase A is a digestive enzyme secreted by the pancreas that hydrolyses phosphodiester bonds in the nucleotide chain. Other RNases are active at the cellular level, for instance in modifying transfer RNA and ribosomal RNA after transcription.

roasting The heating of a finely ground ore, especially a sulphide, in air prior to *smelting. The roasting process expels moisture, chemically combined water, and volatile matter; in the case of sulphides, the sulphur is expelled as sulphur dioxide and the ore is converted into an oxide. Part of the heat may be provided by the combustion of the sulphur.

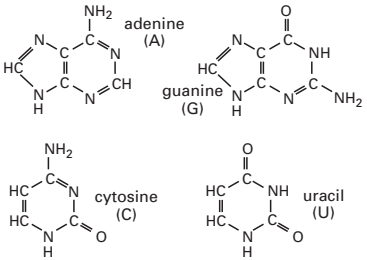
Roche limit The minimum distance from



Detail of molecular structure of sugar–phosphate backbone. Each ribose unit is attached to a phosphate group and a base, forming a nucleotide.



Single-stranded structure of RNA



The four bases of RNA

RNA. Its molecular structure.

the centre of a celestial body at which a satellite orbiting the body can safely remain in equilibrium under the influence of its own gravitation and that of its *primary.

Rochelle salt Potassium sodium tartrate tetrahydrate, $KNaC_4H_4O_6.4H_2O$. A colourless crystalline salt used for its piezoelectric properties. It was first prepared at La Rocelle in France.

Roche lobe One of the two pear-shaped regions that surround each of a pair of *binary stars. It is the region in which a particular star's gravitational field is predominant. It is named after Edouard Roche (1820–83).

Rochon prism An optical device consisting of two quartz prisms; the first, cut parallel to the optic axis, receives the light; the second, with the optic axis at right angles, transmits the ordinary ray without deviation but the extraordinary ray is deflected and can be absorbed by a screen. The device can be used to produce plane-polarized light and it can also be used with ultraviolet radiation.

It was invented by the French astronomer Alexis-Marie de Rochon (1741–1817).

rock An aggregate of mineral particles that makes up part of the earth's crust. It may be consolidated or unconsolidated (e.g. sand, gravel, mud, shells, coral, and clay).

rock crystal *See* QUARTZ.

rocket A space vehicle or projectile that is forced through space or the atmosphere by *jet propulsion and that carries its own propellants and oxidizers. It is therefore independent of the earth's atmosphere for lift, thrust, or oxygen and is the only known vehicle for travel outside the earth's atmosphere. Rocket motors (or rocket engines) are currently driven by solid or liquid chemical propellants, which burn in an oxidizer carried within the rocket. Typical liquid bipropellant combinations include liquid hydrogen with liquid oxygen for main engines and hydrazine with dinitrogen tetroxide oxidizer for smaller positioning rockets. Experimental rocket motors have also been tested using ionized gases and plasmas to provide thrust (*see also* ION ENGINE). The measure of a rocket motor's performance is its *specific impulse.

rocking-chair cell *See* INTERCALATION CELL.

rock salt *See* HALITE.

rock salt structure (sodium chloride structure) A type of ionic crystal structure in which the cations have a face-centred cubic arrangement, with anions occupying all the octahedral holes. It can equally be described as a fcc array of anions with cations in the octahedral holes. Each type of ion has a coordination number of 6. Examples of compounds that have the structure are NaCl, KBr, AgCl, AgBr, HgO, CaO, FeO, NiO, and SnAs.

SEE WEB LINKS

- An interactive version of the structure

rod A type of light-sensitive receptor cell present in the retinas of vertebrates. Rods contain the pigment *rhodopsin and are essential for vision in dim light. They are not evenly distributed on the retina, being absent in the *fovea and occupying all of the retinal margin. *Compare* CONE.

Rodentia An order of mammals characterized by a single pair of long curved incisors in each jaw. These teeth are specialized for gnawing: they continue growing throughout life and have enamel only on the front so that they wear to a chisel-shaped cutting edge. Rodents often breed throughout the year and produce large numbers of quickly maturing young. The order includes the squirrels, beavers, rats, mice, and porcupines.

roentgen The former unit of dose equivalent (*see* RADIATION UNITS). It is named after W. K. Roentgen.

Roentgen, William Konrad (1845–1923) German physicist, who made many contributions to physics, the best known being his discovery of X-rays in 1895. For this work he was awarded the first Nobel Prize for physics in 1901.

roentgenium Symbol Rg. A radioactive transactinide; a.n. 111. It was made by fusion of ^{209}Bi with ^{64}Ni. Only a few atoms have been detected.

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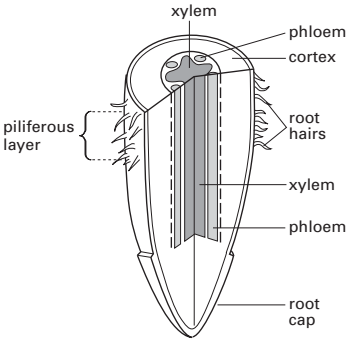
Rohypnol *See* FLUNITRAZEPAM.

rolling friction *Friction between a rolling wheel and the plane surface on which it is rotating. As a result of any small distortions of the two surfaces, there is a frictional force with a component, F_1, that opposes the motion. If N is the normal force, $F_r = N\mu_r$, where μ_r is called the **coefficient of rolling friction**.

ROM Read-only memory. A form of computer memory, fabricated from *integrated circuits, whose contents are permanently recorded at the time of manufacture. It is thus used to store data that never require modification. (The contents of **programmable ROM** (or **PROM**) are recorded in a separate process after manufacture.) Like *RAM it consists of an array of 'cells' to which there is direct and extremely rapid access.

root **1.** (in botany) The part of a vascular plant that grows beneath the soil surface in response to gravity and water. It anchors the plant in the soil and absorbs water and mineral salts. Unlike the stem, it never produces leaves, buds, or flowers and never contains chlorophyll. The *radicle (embryonic root) may give rise either to a **tap root system** with a single main **tap root** from which lateral roots develop, or a **fibrous root system**, with many roots of equal size. The *apical meristem at the root tip gives rise to a protective sheath, the *root cap, and to the primary tis-



Root. Section through the tip of a plant root.

sues of the root. The vascular tissues usually form a central core (see illustration). This distinguishes roots from stems, in which the vascular tissue often forms a ring. A short distance behind the root tip **root hairs** develop from the epidermis and greatly increase the surface area for absorption of water and minerals. Beyond this, lateral roots develop.

Roots may be modified in various ways. Some are swollen with food to survive the winter, as in the carrot. Certain plants, such as orchids, have absorptive aerial roots; others, such as ivy, have short clasping roots for climbing. The roots of leguminous plants, such as beans and peas, contain *root nodules, which have an important role in nitrogen fixation. Other modifications include *prop roots, stilt roots, and buttress roots, which support the plant.
2. (in dentistry) The portion of a *tooth that is not covered with enamel and is embedded in a socket in the jawbone. Incisors, canines, and premolars have single roots; molars normally have several roots.
3. (in anatomy) The point of origin of a nerve in the central nervous system. There are two roots for every *spinal nerve (*see* DORSAL ROOT; VENTRAL ROOT).
4. (in mathematics) **a.** One of the equal factors of a number or quantity, e.g. the cube root of 8 is 2. In general, the *n*th root of a number or quantity a is a number or quantity x that satisfies the equation $x^n = a$. **b.** The value or values of an independent variable in an equation that satisfies that equation.

root cap (calyptra) A cone-shaped structure that covers the root tip and develops as a result of cell division by a meristem at the root apex (*see* CALYPTROGEN). It protects the root tip as it grows between the soil particles. The cells are constantly worn away by friction and are replaced by the meristem.

root hair *See* ROOT.

root-mean-square value (RMS value) **1.** (in statistics) A typical value of a number (n) of values of a quantity ($x_1, x_2, x_3, \ldots$) equal to the square root of the sum of the squares of the values divided by n, i.e.

$$\text{RMS value} = \sqrt{[(x_1^2 + x_2^2 + x_3^2 \ldots)/n]}$$

2. (in physics) A typical value of a continuously varying quantity, such as an alternating electric current, obtained similarly from many samples taken at regular time intervals during a cycle. Theoretically this can be shown to be the **effective value**, i.e. the value of the equivalent direct current that would produce the same power dissipation in a given resistor. For a sinusoidal current this is equal to $I_m/\sqrt{2}$, where I_m is the maximum value of the current.

root nodule A swelling on the roots of certain plants, especially those of the family Fabaceae (Leguminosae), that contains bacteria (notably *Rhizobium*) capable of fixing atmospheric nitrogen into ammonia, which is subsequently converted to nitrates and amino acids (*see* NITROGEN FIXATION). Plants that possess root nodules increase soil fertility by increasing the nitrate content of the soil. The practice of *crop rotation will normally include the cultivation of a leguminous species.

root pressure The pressure that forces water, absorbed from the soil, to move through the roots and up the stem of a plant. This pressure can be demonstrated by cutting a stem, from which water will exude. A *manometer can be attached to a plant stem to measure the root pressure. Root pressure is believed to be due to both the osmosis of water, from the soil into the root cells, and the active pumping of salts into the *xylem tissue, which maintains a concentration gradient along which the water will move. *See also* TRANSPIRATION.

rootstock *See* RHIZOME.

Rose's metal An alloy of low melting point (about 100°C) consisting of 50% bismuth, 25–28% lead, and 22–25% tin.

rot (in mathematics) *See* CURL.

rotary converter A device for converting

direct current to alternating current or one d.c. voltage to another. It consists of an electric motor coupled to a generator.

rotational motion The laws relating to the rotation of a body about an axis are analogous to those describing linear motion. The **angular displacement** (θ) of a body is the angle in radians through which a point or line has been rotated in a specified sense about a specified axis. The **angular velocity** (ω) is the rate of change of angular displacement with time, i.e. $\omega = d\theta/dt$, and the **angular acceleration** (α) is the rate of change of angular velocity, i.e. $\alpha = d\omega/dt = d^2\theta/dt^2$.

The equations of linear motion have analogous rotational equivalents, e.g.:

$\omega_2 = \omega_1 + \alpha t$

$\theta = \omega_1 t + \alpha t^2/2$

$\omega_2{}^2 = \omega_1{}^2 + 2\theta\alpha$

The counterpart of Newton's second law of motion is $T = I\alpha$, where T is the *torque causing the angular acceleration and I is the *moment of inertia of the rotating body.

rotaxane A type of compound that has a dumbbell-shaped molecule with a cyclic molecule around its axis. The dumbbell has a chain with large groups at each end, these being large enough to trap the ring. There is no formal chemical bonding between the dumbbell and the ring. Rotaxanes are examples of compounds with *mechanical bonding. A number of natural peptide rotaxanes have been identified. Synthesis of new rotaxanes is a matter of interest because of their possible use as 'molecular machines' in nanotechnology (e.g. as molecular switches or information storage units).

rotor The rotating part of an electric motor, electric generator, turbine, etc. *Compare* STATOR.

roughage *See* (DIETARY) FIBRE.

rounding error The difference between the exact value of a number and its approximate value that results from considering only a fixed number of decimal places or *significant figures (by rounding up or down). Because only a finite number of *bytes are available to stand for a number in a computer system, computer calculations are subject to rounding errors.

round window (fenestra rotunda) A membrane-covered opening between the middle ear and the inner ear (*see* EAR), situated below the *oval window. Pressure waves transmitted through the perilymph in the *cochlea are released into the middle ear through the round window.

roundworms *See* NEMATODA.

r-process *See* ORIGIN OF THE ELEMENTS.

RQ *See* RESPIRATORY QUOTIENT.

RR Lyrae variable star A type of short-period pulsating *variable star that occurs in globular clusters and in the galactic nucleus. RR Lyrae variables are old population II stars (*see* POPULATION TYPE), typically giant stars whose brightness varies widely every few hours.

rRNA *See* RNA.

R–S convention *See* ABSOLUTE CONFIGURATION.

r* selection** A type of selection that favours organisms with a high rate of reproduction (r* value**). Organisms that are *r* selected (***r* strategists**) are able to colonize a habitat rapidly, utilizing the food and other resources before other organisms are established and begin to compete. They tend to be relatively small with short life spans (e.g. bacteria) and often live in unstable environments; characteristically their survival depends on their ability to produce large numbers of offspring rather than on their ability to compete. *Compare* K SELECTION.

rubber A polymeric substance obtained from the sap of the tree *Hevea brasiliensis*. Crude natural rubber is obtained by coagulating and drying the sap (latex), and is then modified by *vulcanization and compounding with fillers. It is a polymer of *isoprene containing the unit $-CH_2C(CH_3){:}CHCH_2-$. Various synthetic rubbers can also be made. *See* NEOPRENE; NITRILE RUBBER; SILICONES.

rubidium Symbol Rb. A soft silvery-white metallic element belonging to *group 1 (formerly IA) of the periodic table; a.n. 37; r.a.m. 85.47; r.d. 1.53; m.p. 38.89°C; b.p. 688°C. It is found in a number of minerals (e.g. lepidolite) and in certain brines. The metal is obtained by electrolysis of molten rubidium chloride. The naturally occurring isotope rubidium–87 is radioactive (*see* RUBIDIUM–STRONTIUM DATING). The metal is highly reactive, igniting spontaneously in air. It was discovered spectroscopically by Robert Bunsen and Gustav Kirchhoff in 1861.

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rubidium–strontium dating A method of dating geological specimens based on the decay of the radioisotope rubidium–87 into the stable isotope strontium–87. Natural rubidium contains 27.85% of rubidium–87, which has a half-life of 4.7×10^{10} years. The ratio $^{87}Rb/^{87}Sr$ in a specimen gives an estimate of its age (up to several thousand million years).

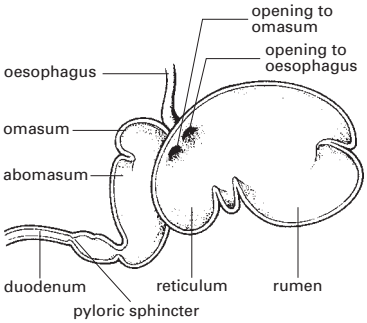
rubisco *See* RIBULOSE BISPHOSPHATE.

ruby The transparent red variety of the mineral *corundum, the colour being due to the presence of traces of chromium. It is a valuable gemstone, more precious than diamonds. The finest rubies are obtained from Mogok in Burma, where they occur in metamorphic limestones; Sri Lanka and Thailand are the only other important sources. Rubies have been produced synthetically by the Verneuil flame-fusion process. Industrial rubies are used in lasers, watches, and other precision instruments.

rumen The second of four chambers that form the stomach of ruminants. *See* RUMINANTIA.

Rumford, Count (Benjamin Thompson; 1753–1814) American-born British physicist, who acted as an English spy during the American Revolution. As a result he was forced to flee in 1775, first to England and then to Munich. There he observed the boring of cannon barrels, which led him to his best-known proposition, that *friction produces heat. While in Munich he was made a count of the Holy Roman Empire. Returning to England in 1795, he helped to demolish the *caloric theory.

Ruminantia A suborder of hooved mammals (*see* ARTIODACTYLA) comprising the sheep, cattle, goats, deer, and antelopes. They are characterized by a four-chambered stomach (see illustration). Swallowed food passes from the first chamber, the **reticulum**, to the **rumen**, where food is digested by *cellulase and other enzymes secreted by symbiotic anaerobic microorganisms that live in the rumen. Some products of digestion are absorbed in the rumen; the remaining partly digested food is regurgitated and chewed to a pulp – the process known as 'chewing the cud'. This food mass is then swallowed and passes from the reticulum to the third chamber, the **omasum**, where water and some nutrients



Ruminantia. Section of the stomach of a ruminant.

are absorbed; and finally to the **abomasum**, in which further digestion takes place.

runner A stem that grows horizontally along the soil surface and gives rise to new plants from axillary or terminal buds. Runners are seen in the creeping buttercup and the strawberry. **Offsets**, e.g. those of the houseleek, are short runners.

Russell–Saunders coupling (L–S coupling) A type of coupling in systems involving many *fermions. These systems include electrons in atoms and nucleons in nuclei, in which the energies associated with electrostatic repulsion are much greater than the energies associated with *spin–orbit coupling. *Multiplets of many-electron atoms with a low *atomic number are characterized by Russell–Saunders coupling. It is named after the US physicists Henry Norris Russell (1877–1957) and F. A. Saunders, who postulated this type of coupling to explain the spectra of many-electron atoms with low atomic number in 1925. The multiplets of heavy atoms and nuclei are better described by *j-j coupling or **intermediate coupling**, i.e. a coupling in which the energies of electrostatic repulsion and spin–orbit coupling are similar in size.

rusting Corrosion of iron (or steel) to form a hydrated iron(III) oxide $Fe_2O_3.xH_2O$. Rusting occurs only in the presence of both water and oxygen. It is an electrochemical process in which different parts of the iron surface act as electrodes in a cell reaction. At the anode, iron atoms dissolve as Fe^{2+} ions:

$$Fe(s) \rightarrow Fe^{2+}(aq) + 2e$$

At the cathode, hydroxide ions are formed:

$$O_2(aq) + 2H_2O(l) + 4e \rightarrow 4OH^-(aq)$$

The $Fe(OH)_2$ in solution is oxidized to Fe_2O_3. Rusting is accelerated by impurities in the iron and by the presence of acids or other electrolytes in the water.

rusts A group of parasitic fungi of the phylum *Basidiomycota. Many of these species attack the leaves and stems of cereal crops: characteristic rust-coloured streaks of spores appear on infected plants. The life cycles of some rusts may be complex; many form a number of different types of spore and some require two different host plants. *Compare* SMUTS.

ruthenium Symbol Ru. A hard white metallic *transition element; a.n. 44; r.a.m. 101.07; r.d. 12.3; m.p. 2310°C; b.p. 3900°C. It is found associated with platinum and is used as a catalyst and in certain platinum alloys. Chemically, it dissolves in fused alkalis but is not attacked by acids. It reacts with oxygen and halogens at high temperatures. It also forms complexes with a range of oxidation states. The element was isolated by K. K. Klaus in 1844.

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Rutherford, Ernest, Baron (1871–1937) New Zealand-born British physicist, who worked under Sir J. J. *Thomson at Cambridge University (1895–98). He then took up a professorship at McGill University, Canada, and collaborated with Frederick *Soddy in studying radioactivity. In 1899 he discovered *alpha particles and beta particles, followed by the discovery of *gamma radiation the following year. In 1905, with Soddy, he announced that radioactive *decay involves a series of transformations. In 1907 he moved to Manchester University, where he directed the *Rutherford scattering experiments that led to the discovery of the atomic *nucleus. After moving to Cambridge in 1919 he achieved the artificial splitting of light atoms. In 1908 he was awarded the Nobel Prize for chemistry.

Rutherford backscattering spectrometry (RBS) A technique for analysing samples of material by irradiation with a beam of alpha particles and measurement of the energies of the alpha particles after they have been scattered by the sample. This enables the elements present and their amounts to be determined because the energy of a scattered alpha particle depends on the mass of the nucleus with which it collides. RBS is used extensively in medicine and industry.

rutherfordium Symbol Rf. A radioactive *transactinide element; a.n. 104. It was first reported in 1964 at Dubna, near Moscow, and in 1969 it was detected by A. Ghiorso and a team at Berkeley, California. It can be made by bombarding californium–249 nuclei with carbon–12 nuclei.

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Rutherford scattering The scattering of *alpha particles by thin films of heavy metals, notably gold. The experiments, performed in 1909 by Geiger and Marsden under Rutherford's direction, provided evidence for the existence of an atomic *nucleus. A narrow beam of alpha particles from a radon source was directed onto a thin metal foil. A glass screen coated with zinc sulphide (which scintillates on absorbing alpha particles) was placed at the end of a travelling microscope and was used to detect scattered alpha particles. The travelling microscope could be rotated about the metal foil; by counting the number of scintillations produced in various positions during equal intervals, the angular dependence of the scattering was determined. Since the range of alpha particles in air is limited, the central chamber of the apparatus was evacuated. Most alpha particles suffered only small angles of deflection. However, a very small number, about 1 in 8000, were deviated by more than an angle $\theta = 90°$.

Rutherford concluded that alpha particles deflected by angles greater than 90° had encountered a small intense positive charge of high inertia. In 1911 he proposed that an atom has a positively charged nucleus, which contains most of the mass of the atom and is surrounded by orbiting electrons (*see* BOHR THEORY). Since very few alpha particles were scattered through large angles, it follows that the probability of a head-on collision with the nucleus is small. The nucleus therefore occupies a very small part of the atomic volume. It is of the order of 10^{-15} m across, whereas the atomic radius is of the order of 10^{-10} m.

rutile A mineral form of titanium(IV) oxide, TiO_2.

rutile structure A type of ionic crystal structure in which the anions have a hexago-

nal close packed arrangement with cations in half the octahedral holes. The coordination number of the anions is 6 and the coordination number of the cations is 3. Compounds with this structure include TiO_2, MnO_2, SnO_2, MgF_2, and NiF_2.

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- An interactive version of the structure

Ruybal test *See* SCOTT'S TEST.

Rydberg constant Symbol R. A constant that occurs in the formulae for atomic spectra and is related to the binding energy between an electron and a nucleon. It is connected to other constants by the relationship $R = \mu_0^2 me^4c^3/8h^3$, where μ_0 is the magnetic constant (*see* PERMEABILITY), m and e are the mass and charge of an electron, c is the speed of light, and h is the *Planck constant. It has the value $1.097 \times 10^7\ m^{-1}$. It is named after the Swedish physicist Johannes Robert Rydberg (1854–1919), who developed a formula for the spectrum of hydrogen.

Rydberg spectrum An absorption spectrum of a gas in the ultraviolet region, consisting of a series of lines that become closer together towards shorter wavelengths, merging into a continuous absorption region. The absorption lines correspond to electronic transitions to successively higher energy levels. The onset of the continuum corresponds to photoionization of the atom or molecule, and can thus be used to determine the ionization potential.

Ryle, Sir Martin (1918–84) British radio astronomer, who became professor of radio astronomy at Cambridge University in 1959. He organized three surveys of celestial radio sources and developed the technique of aperture synthesis (*see* RADIO TELESCOPE). In 1974 he shared the Nobel Prize for physics with Antony Hewish (1924–), who led the team that discovered pulsars.