Ph136abc 2002-2003
Roger Blandford and Kip Thorne [version 02.2]

APPLICATIONS OF CLASSICAL PHYSICS

1. COURSE DESCRIPTION AND PHILOSOPHY

This course was conceived by one of us (Kip), and has been taught for some years by him both of us and other Caltech faculty based on a preliminary draft of a text that we have written. This we shall teach the course jointly, though most of the lecturing will be by Kip, particularly second term when Roger will have other lecturing responsibilities. During the year we shall be making a final revision of the text in preparation for publication. Most significantly, we shall be revising and (hopefully) improving the exercises.

This course is designed to introduce students to the fundamentals of all the major branches of classical physics (except classical mechanics, electromagnetic theory, and elementary thermodynamics, which are learned elsewhere), and also to expose students to many of the exciting modern developments involving classical physics. We regard such a course as important for two reasons: (i) We believe that every PhD physicist should be familiar with the basic concepts and spirit of all the major branches of classical (and also quantum) physics. (ii) A large fraction of Caltech's physics and astronomy graduate students use classical physics extensively in their research and even more of them go on to careers in which classical physics is an essential component. This is not particularly surprising as many of the most important recent developments in physics—and more generally in science and engineering—involve essentially "classical" subjects such as optics, fluid mechanics, kinetic theory, and general relativity.

This course is a survey course designed to accomplish two goals. *First, we seek to give the student a clear understanding of the basic concepts and principles of classical physics.* We present these principles in the language of modern physics (not nineteenth century applied mathematics), and present them for physicists as distinct from mathematicians or engineers. As far as possible, we emphasize theory that involves general principles.

Second, we teach the student how to apply classical physics ideas. We do so by presenting contemporary applications from a variety of fields, such as fundamental physics, experimental physics and applied physics; astrophysics and cosmology; geophysics, oceanography and meteorology; engineering, radio science, and information science. Why is the range of applications so wide? Because we believe that physicists should have at their disposal enough understanding of general principles to attack problems that arise in quite unfamiliar environments. In the modern era, a large fraction of PhD physics students will go on to careers away from the core of fundamental physics. For such students, a broad exposure to non-core applications will be of great value; for those who wind up in the core, such an exposure is of value culturally, and also because ideas from other fields often turn out to have impact back in the core of physics. Our examples will illustrate how basic concepts and problem solving techniques are freely interchanged between disciplines.

The amount and variety of material covered in this course may seem overwhelming. If so, please keep in mind the key goals of the course: to teach the fundamental concepts, which are not so extensive that they should overwhelm, and to illustrate those concepts. The goal is not to master the many illustrations, but rather to learn the spirit of how to apply the concepts.

The course material will also seem much more manageable and less overwhelming when one realizes that the same concepts and problem solving techniques are appearing over and over again, in a variety of different subjects and applications. We shall identify these unifying concepts as the course proceeds and shall remind the student of where they have arisen before.

Classical physics can loosely be defined as the physics where Planck's constant can be approximated as zero. To a large extent, it is the body of physics for which the fundamental equations were established prior to the development of quantum mechanics in the 1920's. Does this imply that it should be studied in isolation from quantum mechanics? Our answer is, most emphatically, "No!". The reasons are simple. *First*, quantum mechanics has primacy over classical physics: classical physics is an approximation, often excellent, sometimes poor, to quantum mechanics. *Second*, in recent decades many concepts and mathematical techniques developed for quantum mechanics have been imported into classical physics and used to enlarge our classical understanding and enhance our computational capability. An example that we shall discuss occurs in plasma physics, where nonlinearly interacting waves are treated as quanta, despite the fact that they are solutions of classical field equations. *Third*, ideas developed initially for "classical" problems are frequently adapted for application to avowedly quantum mechanical subjects; examples are found in supersymmetric string theory and in the liquid drop model of the atomic nucleus. Because of these intimate connections between quantum and classical physics, quantum physics will appear frequently in this course, and in a variety of ways.

The course, when taught all three terms (see below) comprises six parts. We cover statistical physics and optics in the first quarter, elasticity and fluids in the second, and plasmas and general relativity in the third. Each part is organised into chapters; we cover one chapter per week. It is our intention that each quarter can be taken independently, though a considerable degree of cross-referencing is unavoidable and, indeed, helpful. Note that basic electromagnetic theory, classical mechanics and equilibrium thermodynamics, truly classical subjects, are absent. This is because they are usually still part of an undergraduate physics curriculum. We shall assume that the student has some familiarity with these subjects.

Depending on student demand, the course might be taught only first and second terms this year. If so, then **we shall omit:**

- all of general relativity and cosmology [Chapters 23–27] (since a full year course on this is available this academic year),
- two chapters of optics: Diffraction [Chapter 7] and Interference [Chapter 8]
- two chapters of fluid dynamics: Convection [Chapter 17] and additional material, yet to be determined.

With these omisions, the course would consist of:

1. First term: Physics in flat spacetime (Ch. 1), Statistical Physics (Ch's. 2–5), Ge-

ometrical Optics (Ch. 6), Nonlinear Optics (Ch. 9), and Elasticity (Ch's. 10 and 11).

2. Second term: Portions of Fluid Dynamics (Ch's 12–16 with some omissions), and all of Plasma Physics including Magnetohydrodynamics (Ch's 19–22).

The decision about whether the course will be two terms long or three will be made by Kip and Roger, in consultation with the students, no later than the middle of first term. If the third term is taught, Kip will do the lecturing.

2. COORDINATES OF INSTRUCTORS, TA AND WEB SITE.

- **Instructors:**
  * Roger Blandford: 132 Bridge, X4200, rdb@tapir.caltech.edu; administrative assistant — Shirley Hampton, X4597, shirley@tapir.caltech.edu
  * Kip Thorne: 152 Bridge, X4598, kip@tapir.caltech.edu; administrative assistant — Shirley Hampton, X4597, shirley@tapir.caltech.edu
- **Teaching Assistant:**
  * Xinkai Wu: 441 Lauritsen, X4503, xinkaiwu@its.caltech.edu
- **Office Hours:**
  * Blandford or Thorne: will meet students for informal discussion of course material and homework in the Theoretical Astrophysics Interaction Room, room 124 Bridge Annex, at 5:15PM each Monday.
  * Xinkai Wu: Tuesdays 8 to 9 PM in his office, 441 Lauritsen
- **Course Web Site:**
  * http://www.pma.caltech.edu/Courses/ph136/yr2002

3. TEXTBOOK

Drafts of chapters of our textbook will be available on the Web, as postscript files. The entire 2000-2001 version of the book is at

http://www.pma.caltech.edu/Courses/ph136/ph136.html

We are now engaged in a major revision of the book—the last one before publication (we hope!). We therefore urgently request feedback from all class members about the text; not just errata, but also identification of arguments that are muddy, and free wheeling criticism of any sort that you think might be useful to us.

Although the course will follow our textbook, we strongly encourage students to attend lectures rather than relying solely on the book. The amount of material being covered is very great, and it goes by at high speed; the lectures will help in gaining perspective on it and mastering it.

4. HOMEWORK AND GRADING PROCEDURES AND RULES

Problems from the written chapters will be assigned on each Wednesday. Your solutions must be turned in to the instructor *at the beginning of class* (1:00PM) on the following Wednesday. Late homework will not be accepted, unless prior arrangements have been made with one of the TAs—or, at a minimum, a request for an extension has been e-mailed to a TA prior to 1:00PM on the homework due date, and the TA deems the justification for lateness acceptable. In order to turn in homeworks late, you *must have a compellingly legitimate reason*, such as illness or travel in connection with research. Any homework extensions longer than one week must be approved in advance by Blandford or Thorne.

When you turn in your homeworks, you will be given in return a set of solutions that you might find illuminating—or in some cases that set of solutions may be placed on the web. (This is in lieu of discussing the solutions in class.) Some of the same problems have been used in previous years; for them there are many copies of solutions on campus. *You are not allowed to consult those solutions until after your own homeworks have been turned in.* We take very seriously this rule and press for its enforcement under the Caltech honor system.

On the other hand, *you are encouraged to discuss the problems with each other, while you are trying to solve them*, with the proviso that *after the discussions you must write up your solutions yourself, independently of anyone else.*

Some of the homework problems will involve numerical calculations. We presume that all students are computer literate—that, at a minimum, they can use Maple, Mathematica, Macsyma, or some other user-friendly software to generate numerical solutions of equations and to produce two and three dimensional graphs. Any student who is not computer literate should get a student account at CCO or in the East-Bridge computer lab, on a machine that has Maple, Mathematica, or Macsyma, and should invest a day or two in learning to use it.

The default course grades will be Pass-Fail for all students. Students who wish to switch to the ABCDF system can do so by petition through the registrar's office, plus personal arrangement with Blandford or Thorne.

The course grade will be based on homeworks and a final exam in the following manner. Students who score 60% or more on the homeworks will pass the course without having to take the final. If they do not take the final, their grades will be P for people graded PF, and for people with letter grades: homework scores above 90% - A; between 75% and 90% - B; between 60% and 75% - C; below 60% - F. Students who are failing on the basis of homeworks and those who wish to improve their letter grades must take a final examination drawn from 50 elementary questions which will be distributed for study at the last lecture. Eight of these questions must be answered closed book. In this case the homeworks and the exam will both influence the final grade—with the proviso that the exam will never be used to diminish a grade. Past experience has demonstrated that the easiest way to master the material and to pass the course is to do three-quarters of the homework.

5. SOME REMARKS ABOUT THE EXERCISES IN THE TEXT

Each exercise in the textbook is labeled as to type. There are five types:

1. *Practice.* Exercises that give practice at mathematical manipulations (e.g., of tensors).
2. *Derivation.* Exercises that fill in details of arguments or derivations which are skipped over in the text. You are encouraged to read all such exercises, even if they are not assigned to be worked.
3. *Example.* Exercises that lead the reader step by step through the details of some important extension or application of the material in the text. You are strongly urged to read all such exercises, even if they are not assigned to be worked; they are often as important as the text itself.
4. *Problem.* Exercises with few if any hints, in which the task of figuring out how to set the calculation up and get started on it often is as difficult as doing the calculation itself.
5. *Challenge.* An especially difficult exercise whose solution may require you to read other books or articles as a foundation for getting started.