Physics: The First Science

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To Lore, who saw this book come to life,
and was the first to listen to some of its passages.

Preface

The world is a wonderful place. Our aim is that working with this book will help you to be more aware of it than you were before and to see it more fully, both the aspects that are visible and those that are hidden.

Let's look at the different parts of this book. First there is the text. We hope that you find it clear, interesting, and sometimes surprising. We want this to be a book that you *read*. In between the narrative passages are the examples. They turn the words into action. They are essential parts of the book, and it is very important that you read and study them carefully. Each example has questions, usually with numbers and quantities. Working through them is not difficult since the answers are there too.

You might think that leaves nothing for you to do. That's where the "Guided Review" comes in. There is one at the end of each chapter. For each example in the text there is a Guided Review question that is closely related to it. The idea is that as you think about the question at the end of the chapter you will go back to the example that goes with it and study it more closely, and also read and reread the part of the text that goes with it.

The other questions at the end of the chapters are for review, and to let you try out the ideas and the different ways of finding answers. Some of them also take the story further. They are grouped in sections called "Problems and reasoning skill building," "Multiple choice questions," and "Synthesis problems and projects." For simplicity all quantities in the examples and other questions are assumed to be known to three figures unless otherwise noted.

A particularly interesting feature consists of the simulations that have been developed at the University of Colorado. They give you an even closer look at the phenomena that are discussed in the text. In most of them you are asked to make specific measurements, but in addition they invite free explorations that take the concepts further.

We should say a little about the math. That's the language of physics, and it is important to know how to use it. We don't expect you to come knowing more than you learned in high school. But there may be ways of using math that are new to you, and symbols that are different from those that you are used to. We explain them as we go along. We don't use calculus in the problems, but we talk about the ideas of calculus where they are helpful.

The important part of learning physics is not to memorize facts and formulas. It is, rather, to approach and analyze unfamiliar situations. It uses ways of thinking that are accessible to everyone. The study of physics can be frustrating at times, but also exhilarating and rewarding. We hope that you will find it to be an adventure that enriches your view of the world. There may be hard work ahead, but we want you to enjoy the trip that we take together!

Additional Notes, Primarily for the Instructor

We want to change the way physics is taught and the way it is perceived.

We think there is too much rote learning, too many formulas, with too little thought, meaning, and overview. There are too many problems that have no existence outside the elementary physics class, too many that are more like games that the instructors like to play than searching investigations. We want students to see the subject as a vital part of their world, and as a foundation for all of the sciences.

Physics: The First Science is an algebra-based text that is both research based and different from the many textbooks that are currently available. Our book is less than half as long as the tomes that have become the norm, and correspondingly less expensive. It is designed to be read by the students, we hope with interest, and even with pleasure. We would like the students to think of it as contributing to their learning and outlook in an important way, and to remember it long after the course has ended.

The book is supported by the website rutgerspress.rutgers.edu/physics.html. It allows us to post comments, additional material, and corrections, as well as answers and solutions to some of the questions and problems.

We hope that our book will lead to new patterns of teaching. The best courses are transforming experiences. We want to help to create such a course, where the student's view of the world is enriched by a new awareness and understanding of its phenomena.

Some cherished topics are not there. In particular, we have tried to leave out problems that might be called "puzzles." We believe that the teaching of physics should be clear and direct, and we have made great efforts to keep it so.

The topics follow the usual sequence reasonably closely, but we have approached them with a fresh mind, asking ourselves why each is included and how it should be presented. Most topics are there because we think of them as fundamental physics; sometimes because of their importance for technology, their societal relevance, or their historical significance; occasionally we add something that we find beautiful and illuminating, or fun and surprising.

MCAT

Many of the students will want to take the Medical College Admission Test (MCAT). According to the website of the Association of American Medical Colleges, which administers the test, it not only asks for mastery of basic concepts in subjects including physics, but also "assesses capacity for problem solving and critical thinking", and "evaluates your ability to understand, evaluate and apply information and arguments presented in prose style." We have kept the requirements of the test in mind, and believe that our text provides excellent preparation for it.

Examples and end-of-chapter material

The worked examples are an essential part of the reading. They are part of the story line and can't be skipped. They are linked to the *Guided Review* at the end of the chapter, which consists of problems that are alternate versions or minor extensions of the examples. They are fairly simple to do if you read and work through the examples. In that way the Guided Review really forces the student to take the examples and the associated sections of the book seriously. It guides the students' reading and helps them focus on the important concepts. The Guided Review was a very popular feature with the students of the class in which the text was tested.

The end-of-chapter material includes questions beyond the Guided Review in sections called "Problems and reasoning skill building," "Multiple choice questions," and "Synthesis problems and projects." These sections provide plenty of practice. Some of the questions also require thought and creativity well beyond the typical array found in most textbooks and test banks. Note that all quantities in the examples and problems are assumed to be known to three significant figures unless otherwise noted.

Many simulations are incorporated in the text, as examples, as parts of the development, and in the end-of-chapter questions. They provide an excellent way to bring the concepts to life. They were produced by the PhET (Physics Education Technology) project at the University of Colorado, initiated by Carl Wieman, a physicist who decided to devote himself to education after winning the Nobel Prize for his work on atomic physics. Accessing the simulations is quite straightforward, but the students may at first need some guidance. Log onto http://phet.colorado.edu (no www). Then either "play with sims" or "on line" gets you to the list. Click on "physics," then on one of the subdivisions, choose a simulation, and finally "run now." We provide explicit questions, but hope that the students (and the instructor!) will go further and try different parts and possibilities. The PhET group occasionally makes changes to the online simulations so that the instructions may have to be modified, but that should not create major obstacles.

Mathematics

There is no requirement for previous mathematical knowledge beyond high-school algebra. We introduce other mathematics when it is appropriate. Mathematics is part of the language that we use, and we foster the development of mathematical reasoning and physics numeracy. We avoid formulaic use and boxed equations. Most often the mathematical development becomes part of the narrative.

Calculus is not used in the problems, but its ideas are introduced in terms of slopes and areas, and then used where they are relevant, as in the development of kinematics. Chapter 2 reinforces mathematical skills that are both vital in our book and often poorly understood, even by students who are skilled in "doing problems." We encourage the students to use mathematics as a descriptive tool rather than as an algorithmic puzzle solver. We avoid problems that are primarily mathematical exercises.

The road map

Atoms, nuclei, and a modern microscopic view are introduced at the start and referred to frequently. This deviates from the practice of leaving twentieth-century physics ideas until the end of the course. While we think mechanics is important, we are eager to get to other subjects for which there is often too little time. We include an introduction to quantum properties that is earlier and more comprehensive than is usual. We sometimes discuss phenomena on a microscale and sometimes on a macroscale, depending on which is more appropriate.

The first chapter is an overview that introduces atoms and nuclei, scales of size and energy, and the four fundamental forces. It is followed by a review of some of the essential mathematics. The next two chapters are on kinematics and Newton's laws, and make frequent use of multiple representations, such as motion diagrams, graphs, and energy bar charts.

Chapter 5 discusses the nature of models and theories in some detail. It provides an opportunity to think about scientific evidence and the models and theories based on it. Chapter 6 is on energy, not only mechanical but also electric energy and internal energy. Chapter 7 on materials and models is organized somewhat nontraditionally. It includes some kinetic theory, fluids, and the first law of thermodynamics, with remarks on quantum theory and other modern developments.

Chapters 8, 9, and 10 are on electricity and magnetism. Some traditional topics and many traditional problems are left out, but there is some material that is not usually included. The same is true for Chapter 11 on waves, which, in the spirit of the book, deals with sound, light, and electomagnetic waves so as to show their common features and their differences. Chapter 12 is intellectually perhaps the most important chapter. It begins with the "old" quantum theory, including the Bohr model, primarily to introduce some basic quantities and concepts, while making clear from the outset where it is inadequate. The chapter proceeds to the modern synthesis of particles and waves, both for photons and particles, and discusses this fundamental feature of modern physics without resort to mystery or paradox in a way that we think is more straightforward and understandable than most others that we have seen. It is followed by the chapter on nuclear physics, which is quite extensive.

Chapters 14 and 15 represent major departures from the usual subject matter. The chapter *Energy in Civilization*, more than any other, demonstrates the importance of physics in societal issues. It also includes an introduction to entropy and the second law of thermodynamics. We think that it makes these topics more accessible than is usually the case. Finally, we felt that we could not leave out the concepts and devices underlying our electronic age, and end with a chapter that describes some of what is behind the gadgetry that every child now grows up with.

Highways and byways

Even with our drastic cuts, there remains more material in the book than is manageable in the usual one-year course. There are sections, examples, and problems that an instructor may wish to leave out, and others that can be assigned to be read without spending much class time. We are very aware of the need to deal with unfamiliar concepts in some depth and with sufficient time. Each instructor will need to construct his or her own road map. For each part you can choose the level of intensity that you wish to use. The first is to read so as to become familiar with the concepts. The second is to study and be able to make straight-forward applications. Finally, there is the intense involvement that leads to deeper understanding and allows the use of the material in unfamiliar situations. Here are some suggestions for variations.

We like our first chapter, but wouldn't expect to spend a lot of time with it. Similarly, Chapter 2 can be dealt with rather quickly with moderately experienced students. Chapter 5 is short, and much of it can be a reading assignment.

The last section of Chapter 7 consists of topics that are not generally included, and may be assigned as extra reading. It's an advantage to get to the end of Chapter 7 with time to spare, because Chapter 8 on electricity can then be part of the first semester. This allows a fast start to the second semester and additional time for the more sophisticated sections to come. Chapters 8, 9, and 10 are basic, but not everyone will want to deal with each part in the same depth. This applies, for instance, to Gauss's law (in Chapter 8), to the brief part where calculus is used in Chapter 9, and to Section 10.2 on the microscopic aspects of magnetism. The sections on sound (11.3) and light (11.5, 11.6) offer options, and so does the section on relativity in Chapter 11.

Even though Chapter 12 is important, there can be variations in depth and emphasis. We regard most of the first part and the qualitative introduction to the Schrödinger equation as essential, but we realize that the following sections have parts that are more difficult and go far beyond the usual subject matter of a one-year introductory course.

Chapter 13 on nuclear physics is more extensive than usual, but uses only simple algebra. Candidates for bypasses are the semiempirical binding energy relation, and Section 13.6 on the observation of radioactive radiations.

The review of present-day energy use in Chapter 14 may be the first part of the book to be overtaken by what happens. Since it comes near the end it is in danger of being left out. It would be better to assign it as extra reading. It should then be possible to spend some class time on the section on the second law of thermodynamics. Finally, the instructor will have to decide how much time is left for Chapter 15.

In summary, we believe that we have a thoroughly modern course that is open, inviting, and accessible. Some sections are easier and more basic than usual, and some are more sophisticated. Each instructor will have to decide what to include and what to emphasize. Earlier versions of the text were tested during three successive summers at Rutgers University in a course for premed and science majors. The instructor was not one of the authors, but it contributed to the success of the book that he was sympathetic to its aims and ideas, and that the procedures and exams reflected the spirit of the book.

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The book has profited greatly from the contributions of Michael J. Gentile, who was the first to use it as a text in a course. On the basis of this experience he made many thoughtful and helpful comments and suggestions that have led to numerous improvements in the present version.

P. L. and S.W.B.
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