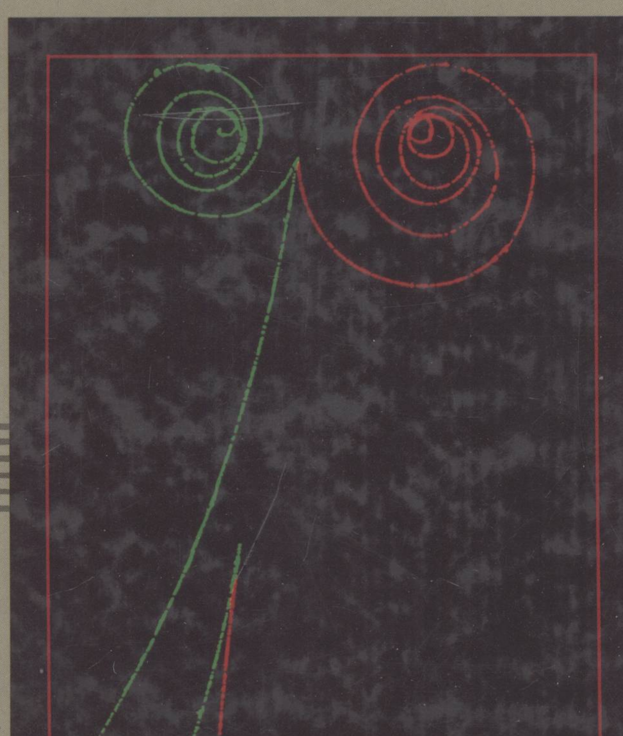
Douglas C. Giancoli

PHYSICS FOR SCIENTISTS AND ENGINEERS



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Douglas C. Giancoli

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PHYSICS
FOR SCIENTISTS AND ENGINEERS

PREFACE

This second edition of *Physics for Scientists and Engineers* is an introductory calculus-based textbook particularly suited for students majoring in physics, other sciences, and engineering. This new edition, with its new, more specific name (in the first edition it was called *General Physics*) retains its major features: it is intended to be readable, interesting, accessible to students, and yet comprehensive, with careful and detailed development of the principles of physics and a strong emphasis on problem solving.

Much of the book has been rewritten for this new edition to increase clarity, to include the most recent important developments, and to give students a more thorough introduction to and more extended treatment of the basic topics, particularly in the chapters on mechanics and those on electricity and magnetism. First, and perhaps foremost, the treatment of Newton's laws has been greatly extended and now occupies two entire chapters (4 and 5). The initial discussion of Newton's laws and their use in solving problems in dynamics is much more detailed than before. Coupled with this is a more extensive treatment of difficult topics, including new material on the Coriolis force and inertial forces in general, and on velocity-dependent forces. (These more advanced topics are marked optional.) The longer and more careful introduction to Newton's laws and their use is of crucial pedagogic importance. The many new worked-out examples include initially fairly simple ones that provide careful step-by-step analysis of how to proceed in solving dynamics problems. Each succeeding example adds a new element or a new twist that introduces greater complexity. It is hoped that this strategy will enable even less well prepared students to acquire the tools for using Newton's laws correctly. For if students do not surmount this crucial hurdle, the rest of physics may remain forever beyond their grasp.

The level of the worked-out examples on Newton's laws thus increases gradually, with the later ones being more complicated than any in the previous edition. Indeed, throughout the book there are many new examples—some of an elementary nature and some that are quite complicated, the latter on a par with the most difficult problems at the end of the chapters, so that students can see how to approach complex problems. In addition, there are more examples illustrating how to do order-of-magnitude (''rough estimate'') calculations. Unlike some others, this text pays careful attention to significant figures: when a certain number is given as (say) 3, with its units, it is meant to be taken as 3 and not assumed to be 3.0 or 3.00.

Among the other chapters or sections extensively revised and rewritten are those on energy (particularly potential energy), rotational motion (especially the extended treatment of translation plus rotation, and—new—the use of instantaneous axis), the wave equation (Chapter 16), Gauss's law and its experimental basis, superconductivity, and other topics in electricity and magnetism. Angular variables and angular kinematics

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are now introduced earlier, in Chapter 3, so that the dynamics of circular motion can be treated in depth with other applications of Newton's laws in Chapter 5. Gravity now occupies its own chapter (6), and there is a new appendix deriving the gravitational force due to a spherical mass distribution.

Even more attention is paid to problem solving in this edition than in the earlier one. Besides the great increase in number and complexity of worked-out examples, the number of problems has been increased significantly. The old problems have been re-checked and in many cases rewritten for greater clarity, most have new numbers, and a few have been deleted. Among the problems, some have been carefully written to spell out a step-by-step procedure leading to the solution. Others merely ask for an answer, so that students have to set up the problem themselves.

As in the first edition, explicit hints on how to attack problems are given in several places early in the book, notably in Sections 2–7, 4–8, and 4–9 ("Notes on Problem Solving"). By the time that students reach the last-named section they will already have had some experience wrestling with problems, and will thus be strongly motivated to read it with close attention. Section 4–9 can, of course, be covered earlier if desired.

A great many of the problems are now illustrated with new drawings. As in the first edition, the problems are arranged by section and are ranked according to difficulty. Level I problems are simple, usually plug-in types, designed to give students confidence; level II are normal problems, requiring thought and often a combination of two or more concepts; level III problems are the most difficult and serve as a challenge to superior students. The arrangement by section number means only that those problems depend on material up to and including that section—earlier sections and chapters are often relied upon, particularly in level II or III problems. SI units are used throughout; British units are defined, but not used. A limited number of problems requiring a computer or programmable calculator are included in some of the chapters, as is a simple discussion (in optional Section 2–10) on how to do numerical integration. Answers to odd-numbered problems are given at the back of the book. Each chapter also contains a set of questions requiring verbal answers.

There are many new figures to illustrate in greater detail the discussions and the problems, and many new photographs: an overall increase of more than a third in the total number of figures. Many of the original figures have been redone for greater clarity. As before, real objects in the drawings (people, tables, balls, planes, etc.) are shown in the second color whereas our analysis (vectors, field lines, graphs, etc.) are shown in black.

The new edition of *Physics for Scientists and Engineers* is available in two versions. This shorter version includes all of classical physics plus two introductory chapters in modern physics: Chapter 40 on special relativity and Chapter 41 on the early quantum theory and models of the atom. A number of modern topics are found in the earlier chapters, such as superconductivity in Chapter 27, and the discovery and properties of the electron, the CRT, and the mass spectrometer in Chapter 29. The longer version contains an additional seven chapters on modern physics, most of which is new material not found in the first edition.

Both versions retain the basic approach of the first edition. Instead of using the common dry approach of treating topics formally and abstractly first, and only later relating the material to the students' own experience, my approach is to recognize that physics is a description of reality and thus to start each topic with concrete observations and experiences that students can directly relate to. Readers are then led into the more formal and abstract treatment of topics. Not only does this make the material more interesting and easier to understand, but it is closer to the way physics is actually practiced. Historically, we didn't start with the second law of thermodynamics, for example, and then derive all kinds of consequences from it; rather, the law was a generalization of all kinds of phenomena.

I have tried to avoid pedantic treatments by making discussions clear and concise, and to eliminate a common fault of dragging out small points to the extent of making them seem big (thus confusing students). On the other hand, I have also tried to avoid the problem of leaving certain topics "hanging," with students wondering "why did we study that?" Thus I have tried to indicate why each topic is important, and to bring each topic to completion. We study static forces in structures, for example, because real materials are elastic and can fracture; so I have included elasticity and fracture in the statics chapter. Having said this, I must mention some exceptions: I have treated a very small number of topics only very briefly (such as Maxwell's equations in differential form) and have not developed them fully. In these few instances the intent was simply to let students know of the existence of certain topics, so that when they meet them again in the future they will at least have seen them before and won't be totally ignorant.

The order of topics remains traditional, but the book allows for considerable flexibility in this order. It begins with mechanics (Chapters 1–15) including fluid mechanics, followed by waves (Chapters 16–17), kinetic theory and thermodynamics (Chapters 18–22), electricity and magnetism (Chapters 23–34), and light (Chapters 35–39). These are followed by the chapters on modern physics discussed on the previous page: two in the shorter version, nine in the longer version.

The tradition of beginning with mechanics is sensible, I believe, since mechanics was developed first, historically, and since so much else in physics depends on it. Within mechanics there are various ways to order the topics. The sequence of the chapters here does not have to be followed precisely. Statics, for example, can be covered either before or after dynamics. I prefer to cover statics after dynamics because many students have trouble with the concept of force without motion. Once they have understood the connection between force and motion, including Newton's third law, they seem to be better able to deal with forces without motion. This order also allows full development of the concept of torque, which is crucial for statics and can be difficult to understand in the absence of motion. Nonetheless, statics (Chapter 12) has been written so that it could be covered earlier, if desired, before dynamics, after a brief introduction to vectors. Another option is presented by the chapters on light. They are placed after the chapters on electricity and magnetism and electromagnetic waves, as is typical. However, light could be treated immediately after the chapters on waves and sound (Chapters 16 and 17), thereby keeping the various types of wave motion in one place. Yet another choice of sequence involves special relativity (Chapter 40), which is discussed after electromagnetic waves and light. Relativity could, however, be covered along with mechanics, say after Chapter 9, since it mainly depends (except for the optional Section 40–2) on material only through Chapter 9.

It is assumed that readers have taken calculus or are taking it concurrently. The derivative is first introduced at the end of Chapter 2 (kinematics) in an optional section. This material can easily be covered later, say when the integral is first discussed in Chapter 7 (Work and Energy). Calculus is treated gently and slowly, especially at first. In fact, throughout the book, each topic is begun at a fairly elementary level so that understanding is accessible to a wide range of students. The rigor normally expected is then quickly reached; and for the most motivated students there are advanced topics (noted as optional by an asterisk), as well as a number of rather difficult problems (ranked level III). Mathematical tools are introduced where they are first needed: the derivative and integral in Chapters 2 and 7, vector addition in Chapter 3, the dot product and cross product in Chapters 7 and 11, respectively, and so on. I believe this method is preferable to lumping the math all in Chapter 1, because it provides motivation for students (they see immediately, for example, why the dot and cross products are defined as they are). A few topics, such as dimensional analysis and order-of-magnitude estimating, are placed in Chapter 1 to make them more visible, rather than being buried at some arbitrary place in the book. These could be covered later, when the need arises.

Some instructors may find that this book contains more material than can be covered comfortably in their courses. But the text can readily be adapted to a shorter course. Sections marked by an asterisk are considered optional. These sections contain slightly more advanced physics material, or material not usually taught at this level, or interesting applications. They contain no material needed in later chapters (except, perhaps, in later optional sections). This does not imply that all nonstarred sections must be covered; there remains considerable flexibility in the choice of material to suit the needs of students and instructors. In addition to optional sections, much or all of Chapters 11 (except Sections 11–1 and 11–2), 12, 13, 14, 24, 32, 33, 40, and 41 could be omitted in a short course, as well as selected parts of Chapters 9, 17, 28, 30, 34, and 36–39. The topics not covered in class can still be read by students, and the book thus provides a valuable resource as a reference book because of its wide range of coverage.

It is necessary, I feel, to pay careful attention to detail, especially when deriving an important result. Whether it is a verbal discussion or a mathematical one, I have aimed at including all steps in a derivation so that students don't get bogged down in details and then fail to understand the concept as a whole. I have tried to make clear which equations are general, and which are not, by explicitly stating the limitations of important equations in brackets next to the equation, such as

$$x = x_0 + v_0 t + \tfrac{1}{2}at^2. \qquad \text{[constant acceleration]}$$

Rotational motion is difficult for most students. As an example of attention to detail (although this is not really a "detail"), I have carefully distinguished the position vector (**r**) of a point and the perpendicular distance of that point from an axis (I call this R, using a small capital). This distinction (which enters particularly in connection with torque, moment of inertia, and angular momentum) is often not made clear in other books—some books use **r** for both without distinguishing, and this can be very confusing to students. Also, I have treated rotational motion by starting with the simple instance of rotation about an axis (Chapter 10), including the concepts of angular momentum and rotational kinetic energy. Only in Chapter 11 is the more general case of rotation about a point dealt with, and this slightly more advanced material can be omitted (except Sections 11–1 and 11–2 on the vector product and the torque vector) if desired.

Among other unusual treatments is Chapter 30, Sources of Magnetic Field: here, in one chapter, are discussed the magnetic field due to currents (including Ampère's law and the law of Biot-Savart) as well as magnetic materials, ferromagnetism, paramagnetism and diamagnetism. This has resulted in a presentation that is clearer, briefer, and more of a whole, and all the content is there. Another is the treatment of conservative forces and conservation of energy in Chapter 8, which is done carefully (showing explicitly, for example, why $W_{1\to 2} = -W_{2\to 1}$ for a conservative force) but without the long-winded confusion that is common. There is a discussion of diffusion (Chapter 19)—unusual for a book at this level, but diffusion is an important topic. Not only is it explained more clearly and simply than in more advanced books, I believe, but "real" diffusion is discussed, not just "self-diffusion."

New to this edition is the greatly expanded supplements package. For instructors, the solutions manual is complete for every problem in the book. For adopters of the text, the following are available: a set of color transparencies of selected figures in the text, a test item file with solutions and explanations, the Prentice-Hall Test Generator and Gradebook software. Free to the students where the text is adopted is a software package that helps students learn problem-solving through interaction and demonstration. Also available to students is a separate study guide that includes chapter overviews, summaries of key terms and mathematics needed and guided problem-solving with solutions to a selected number of problems in the text.

The revision of this book has depended to a great extent on the hundreds of instructors who have used the text in class and were kind enough to send me their comments and suggestions for improvement. To all of them I owe a debt of thanks. I also wish to thank the professors who read through all or much of the text and offered valuable suggestions; these include Austin Napier (Tufts University), Thomas J. Rosener

(U.S. Military Academy, West Point), Somdev Tyagi (Drexel University), Roger Freedman (University of California, Santa Barbara), Everett E. Klontz (Purdue University), Louis Clavelli (University of Alabama, Tuscaloosa), Neil Fleishon (California Polytechnic State University, San Luis Obispo), William E. Fasnacht (U.S. Naval Academy, Annapolis), James H. Smith (University of Illinois, Urbana-Champaign), and Steve Ahlen (Boston University). I am particularly grateful to Roger Freedman, not only for reading the entire manuscript and commenting on it, often wrily (a little levity, especially when so clever, is always welcome), but also for his magnificent work preparing the solutions manual with Thomas Keil and John Reading. I owe special thanks to Professors John Heilbron, Richard Marrus, and Howard Shugart for helpful discussions and suggestions, and for their hospitality at the University of California, Berkeley, as well as to Professor Paolo Galluzzi and the staff of the Institute and Museum of the History of Science, Florence. Finally I wish to thank the many people at Prentice Hall who worked on this project, especially Holly Hodder and Dan Schiller. The responsibility for all errors lies, of course, with me. I welcome comments and corrections.

Douglas C. Giancoli

Notes to Students and Instructors on the Format

1. Sections marked with a star (*) are considered optional.

2. The customary conventions are used: symbols for quantities (such as m for mass) are italicized, whereas units (e.g., m for meter) are not italicized; boldface (**F**) is used for vectors.

3. Few equations are valid in all situations. Where practical, the limitations of important equations are stated in square brackets next to the equation.

4. Figures have been carefully drawn so that real objects (people, tables, the ground, instruments, and so on) are in the second color, whereas our analysis (vectors, field lines, graphs, etc.) are in black.

5. Worked-out examples and their solutions in the text are set off with a vertical colored line in the margin.

6. The number of significant figures (see Section 1–3) should not be assumed to be greater than given: if a number is stated as (say) 6, with its units, it is meant to be 6 and not 6.0 or 6.00 (see also Section 1–7).

7. Each chapter ends with a summary, giving a brief review of important concepts and terms. The summaries are not intended to give an understanding of the material, which can only be had from a study of the chapter.

8. Following the summary in each chapter is a set of questions that students should attempt to answer (to themselves at least). These are followed by problems which are ranked as level I, II, or III according to estimated difficulty, with level I problems being easiest. The problems are arranged by sections, but problems for a given section may require the student to draw on earlier material as well. Questions and problems that relate to optional sections are starred.

9. The appendixes include useful mathematical formulas (such as derivatives and integrals), and a table of isotopes with atomic masses and other data. Tables used frequently are located inside the front and back covers.

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