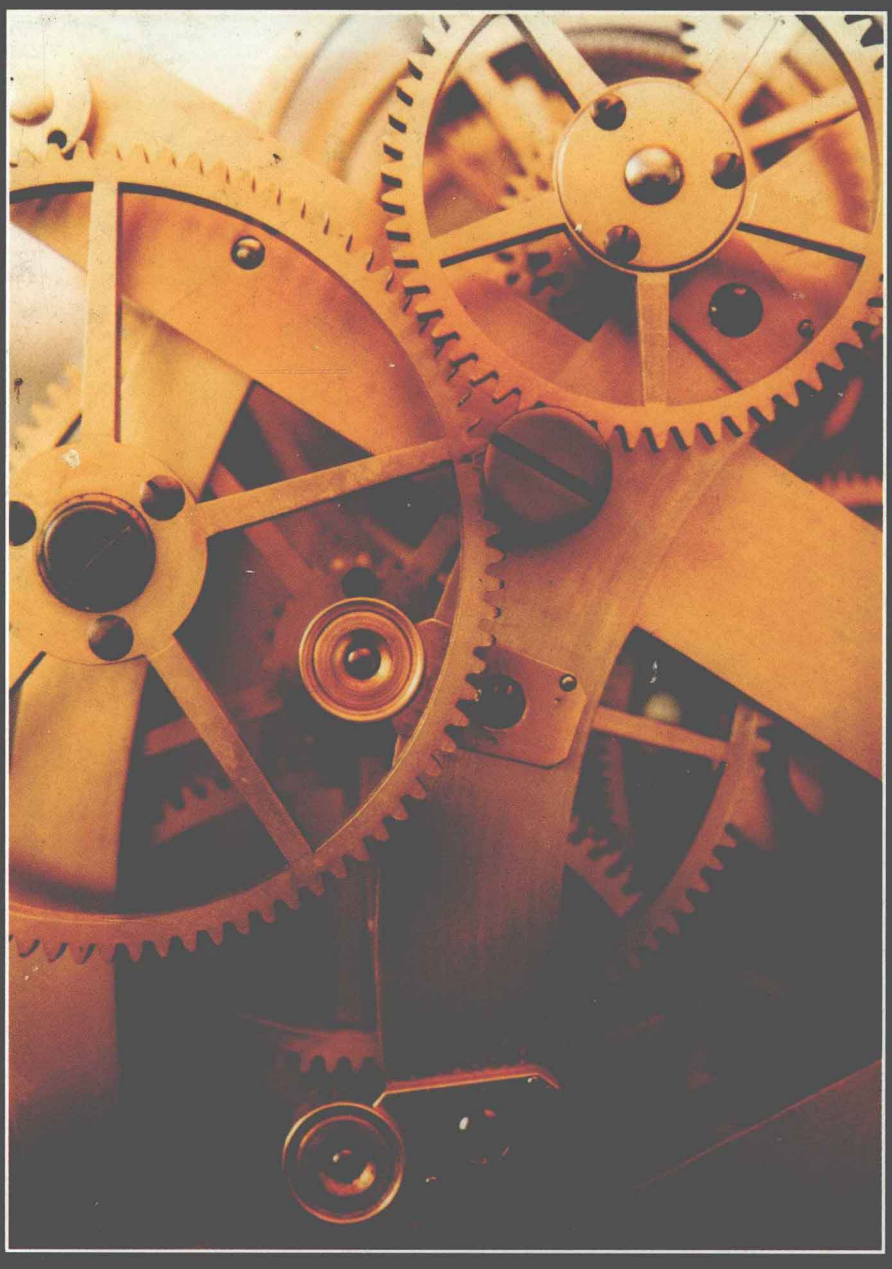

OHANIAN

PHYSICS

SECOND EDITION

Physics

SECOND EDITION

Hans C. Ohanian

RENSSELAER POLYTECHNIC INSTITUTE

W · W · NORTON & COMPANY
NEW YORK · LONDON

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Published simultaneously in Canada by Penguin Books Canada Ltd., 2801 John Street, Markham, Ontario L3R 1B4.
Printed in the United States of America.
Second Edition

Makeup by Roberta Flechner and Ben Gamit.

Cover photograph by Robert Houser, courtesy of Comstock © 1988

Photograph credits appear at back of book.

ISBN 0-393-95746-2

W. W. Norton & Company, Inc., 500 Fifth Avenue, New York, N.Y. 10110
W. W. Norton & Company Ltd., 37 Great Russell Street, London WC1B 3NU

1 2 3 4 5 6 7 8 9 0

Preface

In this Second Edition of *Physics,* I have incorporated divers alterations and additions recommended by the many thoughtful users of the First Edition. My objectives in the book remain the same: to present a contemporary, modern view of classical mechanics and electromagnetism, and to offer the student a glimpse of what is going on in physics today. Thus, throughout the book, I encourage students to keep in mind the atomic structure of matter and to think of the material world as a multitude of restless electrons, protons, and neutrons. For instance, in the mechanics chapters, I emphasize that all macroscopic bodies are systems of particles; and in the electricity chapters, I introduce the concepts of positive and negative charge by referring to protons and electrons, not by referring to the antiquated procedure of rubbing glass rods with silk rags (which, according to experts on triboelectricity, can give the wrong sign if the silk has been thoroughly cleaned). I try to make sure that students are always aware of the limitations of the nineteenth-century fiction that matter and electric charge are continua. Blind reliance on this fiction has often been justified by the claim that engineering students need physics as a tool, and that the atomic structure of matter is of little concern to them. But if physics is a tool, it is also a work of art, and its style cannot be dissociated from its function. In this book I give a physicist's view of physics, because I believe that it is fitting that all students should gain some appreciation for the artistic style of the toolmaker.

Core Chapters and Interludes

The book contains two kinds of chapters: *core* chapters and *interlude* chapters. The 41 core chapters cover the essential topics of introductory physics: mechanics of particles, rigid bodies, and fluids; oscilla-

tions; wave motion; heat and thermodynamics; electricity and magnetism; optics; and special relativity. An expanded version of the book includes another five core chapters covering quantum physics, nuclei, and elementary particles.

The organization of the core chapters is fairly traditional, with some innovations. For instance, I start the study of magnetism (Chapter 30) with the law for the magnetic force between two moving point charges; this magnetic force is no more complicated than the force between two current elements, and the crucial advantage is that magnetism can be developed from the magnetic-force law in much the same way as electricity is developed from Coulomb's Law. This approach is consistent with the underlying philosophy of the book: particles are primary entities and should always be treated first, whereas macroscopic bodies and currents are composite entities which should be treated later. As another innovation, I include a simple derivation of the electric radiation field of an accelerated charge (Chapter 35); this calculation relies on Richtmeyer and Kennard's clever analysis of the kinks in the electric field lines of an accelerated charge (a set of computer-generated film loops available from the Educational Development Center shows how such kinks propagate along the field lines; these film loops tie in very well with the calculations of Chapter 35).

The interlude chapters (the expanded version contains 11) present some of the fascinating discoveries and applications of physics today: crystal structure and symmetry, the expansion of the universe, automobile safety, ionizing radiation, energy resources, atmospheric electricity, plasmas, superconductivity, general relativity, lasers, and fission. All of these interludes are optional—they rely on the core chapters, but the core chapters do not rely on them. Users of the First Edition will perceive that Chapter 46, on elementary particles, was an interlude in the First Edition. It has now been recast as a core chapter to round out the set of core chapters covering modern physics. However, it remains an interlude in spirit, and can be treated as such.

The inspiration for the interludes grew out of my unhappiness over a paradox afflicting the typical undergraduate physics curriculum: liberal-arts students in a nonmathematical physics course often get to see more of the beauty and excitement of today's physics than do science and engineering students in a calculus-based physics course. While liberal-arts students get a glimpse of gluons, black holes, or the Big Bang, science and engineering students are expected to calculate the motion of blocks on top of other blocks sliding down an inclined plane, or the motion of a baseball thrown in some direction or another by a man (or woman) riding in an elevator. To some extent this is unavoidable—science and engineering students need to learn and practice classical mechanics and electromagnetism, and they have little time left for dabbling in the arcane mysteries of contemporary physics. Nevertheless, most teachers will occasionally find an hour or two to tell their students a little of what is going on in physics today. I wrote the interludes to lend encouragement and support to such excursions to the frontiers of physics.

My choice of topics for the interludes reflect the interests expressed by my students. Over the years, I have often been asked: When will we get to quarks? or Are you going to tell us about gravitational collapse? and I came to feel that such curiosity must not be allowed to wither away. Obviously, in the typical introductory course it will be impossible to cover all of the interludes (I have usually covered two per term), but

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the broad range of topics will permit teachers to select according to their own tastes. The interludes are mainly descriptive rather than analytic. In them, I try to avoid formulas and instead give students a qualitative feeling for the underlying physics, keeping the discussion simple so that students can read them on their own. Thus, the interludes could be used for supplementary reading, not necessarily accompanied by lectures. For the inquisitive student, each interlude includes a collection of qualitative questions and an extensive annotated list of further readings.

Optional Sections and Chapters

Optional sections and chapters have been indicated by a large asterisk (*). All such optional sections or chapters and all the interludes can be omitted without loss of continuity. Some other sections and chapters could possibly be omitted. For the guidance of teachers, the outline of quintessentials attached to this Preface lists all the sections that are indispensable for the logical coherence of the text.

Mathematical Prerequisites

In order to accommodate students who are taking an introductory calculus course concurrently, derivatives are used slowly and hesitantly at first (Chapter 2), and routinely later on. Likewise, the use of integrals is postponed as far as possible (Chapter 7), and they come into heavy use only in the second volume (after Chapter 21). For students who need a review of calculus, Appendix 5 contains a concise primer on derivatives and integrals.

Examples, Problems, Questions, and Summaries

The core chapters include generous collections of solved examples (about 300 altogether), of qualitative questions for review (about 850 altogether), and of problems (about 2150 altogether). Answers to the even-numbered problems are given in Appendix 11. The problems are grouped by sections, with the most difficult problems at the end of each section. The levels of difficulty of the problems are roughly indicated by no star, one star (*), or two stars (**). No-star problems are easy and straightforward; they are mostly of the plug-in type. One-star problems are of medium difficulty; they contain a few complications requiring the combination of several concepts or the manipulation of several formulas. Two-star problems are difficult and challenging; they demand considerable thought and perhaps some insight, and they occasionally demand substantial mathematical skills.

I have tried to make the problems interesting to the student by drawing on realistic examples from technology, sports, and everyday life. Many of the problems are based on data extracted from engineering handbooks, car-repair manuals, *Jane's Book of Aircraft, The Guinness Book of World Records,* newspaper reports, etc. Many other problems

deal with atoms and subatomic particles; these are intended to reinforce the atomistic view of the material world. In some cases, cognoscenti will perhaps consider the use of classical physics somewhat objectionable in a problem that really ought to be handled by quantum mechanics. But I believe that the advantages of familiarization with atomic quantities and magnitudes outweigh the disadvantages of a naïve use of classical mechanics.

Each chapter also includes a collection of qualitative questions intended to stimulate thought and to test the grasp of basic concepts (some of these questions are discussion questions that do not have a unique answer). Moreover, each chapter contains a brief summary of the main physical quantities and laws introduced in it. The virtue of these summaries lies in their brevity. They include essential definitions and equations, because the statements in the body of each chapter are adequate.

Units

The SI system of units is used exclusively. In the abbreviations for the units, I follow the dictates of the Conférence Générale des Poids et Mesures of 1971, although I deplore the majestic stupidity of the decision to replace the old, self-explanatory abbreviations amp, coul, nt, sec, °K by an alphabet soup of cryptic symbols A, C, N, s, K, etc. For the sake of clarity, I spell out the names of units in full whenever the abbreviations are likely to lead to ambiguity and confusion.

For reference purposes, the definitions of the British units have been retained. But these units are not used in examples or in problems, with the exception of a handful of problems in the first chapter. In the definitions of the British units, the pound (lb) is taken to be the unit of mass, and the pound-force (lbf) is taken to be the unit of force. This is in accord with the practice approved by the American National Standards Institute (ANSI), the Institute of Electrical and Electronic Engineers (IEEE), and the United States Department of Defense.

Changes from the First Edition

In response to comments from users of the First Edition, I have reorganized some chapters and added some new chapters and sections to provide more thorough and better-balanced coverage. The discussion of angular momentum, which used to be dispersed over two chapters, now appears in one place, in Chapter 12. The discussion of the magnetic force between moving charges in Chapter 30 has been made clearer and simpler. Concise, but self-contained, introductions to dot and cross products of vectors have been included where they are first needed (Chapters 7 and 12, respectively); this makes the book more flexible, since it is now possible to skip the sections on these products in Chapter 3. The chapter on gravitation has been moved forward, so it now precedes the discussion of systems of particles; this move seems sensible since all the simple problems in gravitation assume a fixed center of force, and they can therefore be regarded as single-particle problems. The chapter on special relativity and the chapter on elementary particles have been moved toward the end of the book, in accord

with their historical position. However, the prerequisites for these two chapters have not been changed appreciably, and students could read them much sooner, during the first half of the course.

Several new chapters have been added: (14) "Statics and Elasticity"; (38) "Mirrors, Lenses, and Optical Instruments"; (44) "Quantum Structure of Atoms, Molecules, and Solids"; (45) "Nuclei"; and a new Interlude III, "Automobile Collisions and Automobile Structure." The sections that have been added are: 1.7 Significant Figures, Conversion of Units, and Consistency of Units; 19.3 Kinetic Pressure and the Maxwell Distribution; 19.5 The Mean Free Path; 20.3 Thermometers and Thermal Equilibrium; 29.6 Electrical Measurements; 29.7 The RC Circuit; 32.7 The RL Circuit; and 37.4 Polarization.

Besides these additions, the new edition incorporates a multitude of stylistic and pedagogical improvements. For instance, *Comments and Suggestions* have been appended to many of the solved examples in the text; these comments point out generalizations and/or special features of the results, and they provide the student with helpful hints on how to apply (and how not to apply) the methods illustrated in the examples to the solution of problems.

The number of solved examples and of problems has been increased by about 25%, and more attention has been paid to achieving a balance among examples and among problems of diverse levels of difficulty.

Study Guide

An excellent study guide for this book has been written by Professors Van E. Neie (Purdue University) and Peter J. Riley (University of Texas, Austin). This guide includes for every chapter a brief introduction laying out the objectives; a list of key terms for review; detailed commentaries on each of the main ideas; and a large collection of interesting sample problems, which alternate between worked problems (with full solutions) and guided problems (which provide step-by-step schemes that lead students to the solutions). Those with Macintosh computers should also be aware of an exciting new project by Eric Mazur (Harvard University).His software gives access to any of its three component parts: interactively solved problem, demonstrations, and summary notes.

Acknowledgments

I have greatly benefited from comments by reviewers and users of the book. Many of the alterations in this Second Edition originated from users who, to my pleasant surprise, took the trouble to send me their recommendations for improvements, and sometimes even sent me data for the construction of additional realistic and interesting problems. For very detailed, comprehensive reviews, I am indebted to John R. Boccio (Swarthmore College), Roger W. Clapp, Jr. (University of South Florida), A. Douglas Davis (Eastern Illinois University), Anthony P. French (Massachusetts Institute of Technology), J. David Gavenda (University of Texas, Austin), Roger D. Kirby (University of Nebraska), Roland M. Lichtenstein (Rensselaer Polytechnic Institute), Richard T. Mara (Gettysburg College), John T. Marshall (Louisiana

State University), Delo E. Mook (Dartmouth College), Harvey S. Picker (Trinity College), Peter J. Riley (University of Texas, Austin), and Peter L. Scott (University of California, Santa Cruz). For briefer reviews, I am indebted to John R. Albright (Florida State University), I. H. Bailey (Western Australia Institute of Technology), Frank Crawford (University of California, Berkeley), Sumner Davis (University of California, Berkeley), John F. Devlin (University of Michigan, Dearborn), Phil Eastman (University of Waterloo, Canada), Hugh Evans (University of Waterloo, Canada), Frank A. Ferrone (Drexel University), James R. Gaines (Ohio State University), Stephen Gasiorowicz (University of Minnesota), Michael A. Guillen (Harvard University), Lyle Hoffman (Lafayette College), Walter Knight (University of California, Berkeley), Jean P. Krisch (University of Michigan, Ann Arbor), L. B. Meyer (Duke University), Frank Moscatelli (Swarthmore College), Hermann Nann (Indiana University), Mette Owner-Peterson (The Technical University of Denmark), Norman Pearlman (Purdue University), P. Bruce Pipes (Dartmouth College), Jack Prince (Bronx Community College), Malvin Ruderman (Columbia University), Kenneth Schick (Union College), Mark P. Silverman (Trinity College), Gerald A. Smith (Michigan State University), Julia A. Thompson and David Kraus (University of Pittsburgh), Som Tiagi (Drexel University), and Gary A. Williams (University of California, Los Angeles). I am also indebted to the experts who reviewed the interludes: Edmond Brown (Rensselaer Polytechnic Institute; "The Architecture of Crystals"), Priscilla W. Laws (Dickinson College; "Radiation and Life"), Alan H. Guth (Massachusetts Institute of Technology; "The Big Bang and the Expansion of the Universe"), Frank Richardson (National Highway Traffic Safety Administration; "Automobile Collisions and Automobile Structure"), Donald F. Kirwan (University of Rhode Island; "Energy, Entropy, and the Environment"), Irving Kaplan (Massachusetts Institute of Technology; "Nuclear Fission"), Bernard Vonnegut (State University of New York at Albany; "Atmospheric Electricity"), Sam Cohen (Princeton University Plasma Physics Laboratory; "Plasma"), and Margaret L. A. MacVicar (Massachusetts Institute of Technology; "Superconductivity").

I thank Richard D. Deslattes and Barry N. Taylor of the National Bureau of Standards for information on units, standards, and precision measurements. I thank some of my colleagues at Union College: C. C. Jones prepared the beautiful photographs of interference and diffraction by light (Chapters 39 and 40); Barbara C. Boyer gave valuable advice and assistance on photographs dealing with biological material; and the staff of the library helped me find many a tidbit of information needed for an example or a problem.

I thank the editorial staff of W. W. Norton & Co. for their zeal. Drake McFeely, editor, gave this Second Edition the same meticulous attention he gave the First, and he was indefatigable in collecting comments from reviewers and users. Avery Hudson supervised all aspects of the production process; he also improved my sentences, and helped me to attain a high level of stylistic consistency in the text and in the diagrams. And Ruth Mandel provided the detective work needed to find the many splendid new photographs that have been added to the book.

H. C. O.
February 1989

Quintessentials

The sections in the following list are indispensable for the logical coherence of the text. Teachers pressed for time can take this list of quintessentials as a base line, and add sections to suit their personal preferences.

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Chapter 3: 3.1, 3.2, 3.3
Chapter 4: 4.1, 4.2, 4.4
Chapter 5: all
Chapter 6: 6.2, 6.3, 6.5, 6.7
Chapter 7: all
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Chapter 19: 19.1, 19.2, 19.3
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Chapter 22: all
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Chapter 24: all
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