Kenneth W. Ford

Classical and Modern Physics

Volume I

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Volume 1

Classical and Modern Physics

A TEXTBOOK FOR STUDENTS OF SCIENCE AND ENGINEERING

XEROX COLLEGE PUBLISHING *Lexington, Massachusetts | Toronto*

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ISB Number: 0-536-00723-3 (Domestic)
ISB Number: 0-536-00870-1 (International)
Library of Congress Catalog Card Number: 76-161385
Printed in the United States of America.

Classical and Modern Physics

THIS BOOK IS AVAILABLE IN THREE VOLUMES
AND IN A COMBINED EDITION OF VOLUMES 1 AND 2

In Volume 1

Introduction to Physics
Mathematics
Mechanics

In Volume 2

Thermodynamics
Electromagnetism

In Volume 3

Relativity
Quantum Mechanics

Classical and Modern Physics

Preface

This is a textbook for a three-semester introductory physics course for students of science and engineering. Roughly the first two-thirds of the book (Parts 1–5) could serve as a text for a one-year course in classical physics; the last third (Parts 6 and 7) could serve as a text for a one-semester course in modern physics. With certain sections and subsections—or even whole chapters—omitted, it should also meet the needs of a one-year course that includes modern physics. Because of its substantial length and because of the several kinds of courses in which it might be used, the book is published in three volumes as well as in a combined edition of Volumes 1 and 2. The parts of the volumes are as follows:

Volume 1 1. *Introduction to Physics*
2. *Mathematics*
3. *Mechanics*

Volume 2 4. *Thermodynamics*
5. *Electromagnetism*

Volume 3 6. *Relativity*
7. *Quantum Mechanics*

The appendices and the index for the complete book appear in each volume.*

Probably every author has in mind a particular kind of student for whom he is writing. My "model student" has had high-school physics and is taking calculus concurrently with college physics. He or she is a serious but not necessarily gifted student, is interested in ideas as well as technical skills, and

* This early printing of Volume 1 contains an index for Parts 1–4 only.

learns best when mathematical derivations are supplemented by verbal explanations and physical examples. In terms of the intellectual demand placed on the student, this text is comparable to the popular text by Halliday and Resnick.* It is less demanding than the Berkeley Physics Course† or the M.I.T. Introductory Physics Series.‡

As originally conceived, this book was to be a "calculus version" of my earlier text, *Basic Physics*.§ Having passed through numerous evolutionary stages of writing and rewriting, deleting and adding, however, the book as now published is distinct from the earlier one in various ways besides its mathematical level.

Some of the principal features of this text are the following: (1) I have tried to give a unified presentation of both classical and modern physics. Although theoretical developments of relativity and quantum physics are saved for the last two parts of the book, certain ideas (mass-to-energy conversion, for instance, and nature's speed limit) are introduced early, and modern examples often serve to illustrate classical laws. (2) A series of introductory chapters give time for some maturing of the student's view of physics and his command of mathematics before the intricacies of classical mechanics are approached. (3) Ideas of calculus are introduced (in Chapter 5) somewhat more fully than in most other physics texts. (4) I have tried to steer a course through the discipline of physics that keeps the student in touch with the large view of the subject—the economy and simplicity of its concepts, the elegance of its overall structure—at the same time that he is mastering practical skills and polishing his problem-solving ability. (5) As aids to study and review, the text is divided into fairly numerous sections and subsections, marginal notes highlight key ideas and important equations, and summaries of ideas and definitions appear at the end of every chapter. (6) I have tried to bring out the excitement of physics as a living, evolving discipline, powerful yet incomplete. A limited amount of historical material is included; I have taken some care with this and hope that most of it is real history and not myth.

The "Notes on the Text" that begin on page xiii are intended as a brief guide to instructors. Students, too, can be encouraged to read these notes. As an aid to selective use of the material, some sections and subsections are marked with a star (★) to indicate that they are optional. A section or subsection may be so marked either because it is of greater than average difficulty or because it is peripheral to the main development of a chapter. Any such designation of optional material is necessarily rather arbitrary. Most instructors will have their own ideas about which material to include and which to omit; the stars provide only a first set of suggestions.

At the end of each chapter appear questions, exercises, and problems. *Questions*, with few exceptions, are to be answered in words. Many of them are intended to be thought-provoking and may have no specific right answer.

* David Halliday and Robert Resnick, *Physics* (New York: John Wiley and Sons, Inc., 1966).

† *The Berkeley Physics Course*, a five-volume series by various authors (New York: McGraw-Hill Book Co.).

‡ *The M.I.T. Introductory Physics Series*, three volumes by A. P. French in print in 1971, with three more volumes scheduled (New York: W. W. Norton and Co.).

§ Xerox College Publishing, 1968.

Some are difficult. *Exercises* are intended to be straightforward tests of understanding of the material in the chapter without special twists or subtleties. The exercises involve numerical work as well as algebra and some calculus. Often an exercise may ask for a brief explanation as well as a quantitative result. *Problems* are, in general, more challenging. They may be in the nature of difficult exercises; they may draw together material from more than one section; or they may build on material in the text but go somewhat beyond it. The number of questions, exercises, and problems is large—much larger than the number that would ordinarily be assigned in a course. This large number is provided in order to meet the needs and tastes of different instructors, to enable the student to practice on items that are not assigned, and to enable the instructor, if he wishes, to choose examination questions from the text. Because the chapters are rather long and the end-of-chapter items are numerous, marginal notes are used to classify the questions, exercises, and problems. Questions and exercises are keyed to specific sections. Problems are labeled by their subject.

I have used SI (mks) units throughout. Some special units—such as the calorie, the astronomical unit, and the electron volt—are introduced, and some exercises and problems require conversion of units. However, no effort is made to have the student develop any routine familiarity with more than one set of units. To aid the student in case he encounters Gaussian (cgs) units in another text or in a research paper, Appendix 5 contains an extensive list of the equations of electromagnetism in SI and Gaussian units. My only significant deviation from "purity" in handling units occurs in Chapters 13 and 14, where calories and kilocalories are used as often as joules and where Avogadro's number is defined as the number of molecules in 1 mole rather than the number in 1 kmole.

I want students to enjoy this book and to profit from it. I think it will serve its purpose best if students are not rushed too quickly through too much of it. Careful treatment of some material and judicious omission of other material will probably provide better preparation for further work in physics, engineering, and other sciences than will a fast trip through every section.

KENNETH W. FORD

Acknowledgments

I have had the great benefit of collaboration with Neal D. Newby, Jr., and Brenton F. Stearns on questions, exercises, and problems. Their hundreds of suggestions for end-of-chapter items were vitally important when my own imagination began to flag. In his role of Consulting Editor, Brenton Stearns has also been of inestimable value as careful reader and thoughtful critic throughout the writing and rewriting of this text. I am indebted to Russell K. Hobbie, Donald E. Schuele, and N. S. Wall, who read one draft of the manuscript, and to David J. Cowan, who read two, for their numerous helpful suggestions. So many colleagues have contributed facts, data, photographs, and suggestions that a complete list is impossible. Among them are Olexa-Myron Bilaniuk, Alfred M. Bork, George J. Igo, Henry H. Kolm, Alexander Landé, Arthur W. Martin, Edward M. Purcell, Frederick Reines, Gerald Schubert, and Barry N. Taylor.

Yale Altman and Warren Blaisdell encouraged the initiation of this project and helped to keep it going. They deserve the credit (or blame) for turning me into an author in the first place. At Xerox College Publishing, James Piles has been an agreeable and helpful mentor, and Bernice Borgeson has handled thousands of details with extraordinary dedication. I have been fortunate in having the services of two outstanding typists, Lisa Munsat and Elizabeth Higgins.

Notes on the text

Of the book's seven sections, the first two (*Introduction to Physics* and *Mathematics*) provide introductory and background material. There is great latitude in the way these two parts may be used. The remaining five parts (*Mechanics*, *Thermodynamics*, *Electromagnetism*, *Relativity*, and *Quantum Mechanics*) are devoted to specific major theories of physics. The fullest mathematical development is carried out for the theories of mechanics, electromagnetism, and special relativity. Thermodynamics and quantum mechanics are handled with somewhat more attention to phenomena and less to mathematical formalism. (Nevertheless, I have avoided more modest titles, such as *Heat* and *Atomic and Nuclear Phenomena*, because these parts do also emphasize the unity and power of physical theories, and they are by no means lacking in mathematics.) The division of the book into parts and the choice of rather long chapters in preference to more numerous shorter chapters are designed to serve the same end: to keep the overall structure of physics in view at a time when it is all too easy for the student to see the subject as a bewildering array of unrelated pieces.

PART 1: Chapter 1 provides a brief overview of physics—its relation to mathematics and technology, its division into theory and experiment, and its development over the past few centuries. I recommend that students be asked to read this short chapter and to consider some of the questions at the end even if it receives very little class time.

For students who have previously had a physics course, most of what is in Chapter 2 will be review and consolidation of material studied earlier. Students coming to physics for the first time will want to pay closer attention to this chapter. The chapter has several goals: to introduce SI units and define standards, to provide qualitative insights into the meaning of various important concepts, and to provide useful hints on dimensional consistency and units arithmetic.

Chapter 3 is an optional chapter that can be omitted without lack of continuity or be assigned to be read "for fun." There are, however, some serious reasons for putting a survey of elementary particles and submicroscopic nature near the beginning of a general physics text, and these are discussed in Section 3.1. Particles are used from time to time in later parts of the book for illustrative purposes, but these uses do not presuppose an assimilation of all the material in Chapter 3.

The seven absolute conservation laws considered in Chapter 4 introduce an important theme and reveal some common elements of classical and modern physics. Just as the concepts discussed in Chapter 2 are refined in later chapters, most of the laws discussed in this chapter are developed more elaborately later. An instructor who prefers to move rapidly toward kinematics and Newton's laws could omit this chapter or postpone it until reaching Chapters 8, 9, and 10, where the laws of conservation of momentum, angular momentum, and energy reappear.

PART 2: The consolidation of most (but not all) of the mathematical developments in the book in this early part gives the instructor flexibility. He may pause to consider mathematical topics by themselves, or he may skip some sections of Chapters 5 and 6 and refer back to them later. Although entitled "Mathematics," this part does contain considerable physics. See in particular the kinematics in Sections 5.7 and 6.10 and the discussion of experimental uncertainty in Section 5.12. Some mathematical topics that are saved for later chapters are the idea of partial differentiation (Chapter 10), the line integral (Chapter 10), and the surface integral (Chapter 15).

In Chapter 5, differentiation and integration are developed more fully than in most other physics texts. These sections cannot, of course, substitute for a mathematics course, but they can help the student to gain a more intuitive grasp of what he is learning in mathematics and see how to apply it to physical situations. Sections 5.3–5.11 are devoted to essential practical matters. Sections 5.1 and 5.2 are quite different; they are devoted to the nature of mathematics and its relation to science. Section 5.12 ought to be most effective if used in conjunction with laboratory work; it is not essential for further developments in this text.

Most of Chapter 6 does not differ greatly from many standard introductions to vectors. At the beginning, it ties vector algebra to the geometrical arithmetic that students now learn in school. Optional sections treat the transformation of components and the distinction between polar vectors and axial vectors. Some care is taken in the chapter to distinguish a physical vector quantity from a mathematical vector and to emphasize that the vector nature of a physical quantity must be decided by experiment.

PART 3: Chapters 7–10 can be thought of as an ascending staircase of increasing difficulty and sophistication. The formal development of mechanics is essentially completed in these four chapters. Chapter 11 should then come as a welcome relief to the student. Chapter 12 is an assortment of distinct supplementary topics, any combination of which could be included to round out the study of mechanics.

Newton's first and second laws appear in Chapter 7. In addition to numerous standard applications, this chapter includes discussions of frames of reference, the distinction between inertial and gravitational mass, the significance of Newton's first law, and the logical structure of mechanics—especially the question of the intermingling of laws and definitions.

Newton's third law is placed in a separate chapter (Chapter 8) to emphasize that it is quite a different sort of law from Newton's first and second laws and to bring out its special connection to the concept of momentum. Chapter 7 was devoted to particle mechanics; Chapter 8 is devoted to systems. A discussion in Section 8.5 ties together the two chapters and shows the interconnections of Newton's three laws. Section 8.12 is related to an earlier discussion of momentum conservation in Chapter 4.

In Chapter 9, angular momentum is defined for particles and is then generalized to systems. Throughout the chapters I have tried to give a balanced and unified view of angular momentum for bodies moving through space and bodies rotating about fixed axes. To this end, orbital angular momentum and spin angular momentum are introduced in Section 9.3. Preliminary to Chapter 11, the law of areas (Kepler's second law) is introduced in Section 9.9. The consideration of rotational energy is postponed to Section 10.9.

In the interest of logical development I have put a full treatment of work and kinetic energy in the first four sections of Chapter 10, even though the last part of Section 10.3 and all of Section 10.4 are more difficult than what follows in the next few sections. This optional material can be omitted or postponed. Examples in Section 10.7 are repeated in Section 10.8 in order to add the important element of the energy diagram to their analysis. The simple pendulum, treated late in the chapter (Section 10.11), should not be overlooked.

Chapter 11 is devoted to the single subject of gravitation because of the fundamental importance of gravitation in nature and because of its importance historically in the genesis of mechanics and modern science. As noted earlier, this chapter is less demanding than those that immediately precede it.

All of Chapter 12 may be considered optional. Any choice could be made from among its five nearly independent topics: surface friction, statics of rigid bodies, fluids, frictional air drag, and two-body collisions.

Contents

PART I *Introduction to Physics*

* Sections and subsections marked with stars are optional.

PART III *Mechanics*

9 ANGULAR MOMENTUM 316

10 ENERGY 376

11 GRAVITATION 443

12 FURTHER APPLICATIONS OF MECHANICS 489

APPENDICES