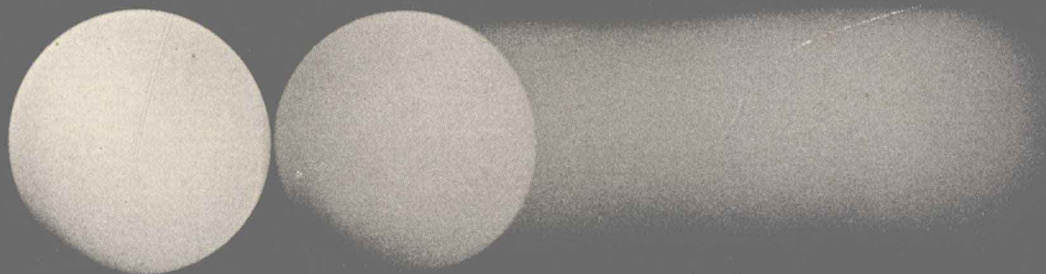
UNDAMENTALS OF MECHANICS AND HEAT



Fundamentals of Mechanics and Heat

HUGH D. YOUNG

Associate Professor of Physics
Head, Department of Natural Sciences
Margaret Morrison Carnegie College
Carnegie Institute of Technology

McGraw-Hill Book Company

NEW YORK SAN FRANCISCO TORONTO LONDON

Library of Congress Catalog Card Number 63-22642

72635

67891011 HDBP 7543210

McGraw-Hill Series in Fundamentals of Physics

INTRODUCTORY PROGRAM

E. U. Condon, Editor

FUNDAMENTALS OF MECHANICS AND HEAT

by Hugh D. Young

FUNDAMENTALS OF ELECTRICITY AND MAGNETISM

by Arthur F. Kip

FUNDAMENTALS OF OPTICS AND MODERN PHYSICS

by Hugh D. Young

Fundamentals of Mechanics and Heat

Preface

NO ONE MUST be persuaded nowadays that a thorough course in the fundamentals of physics is an essential part of the curriculum of every beginning student of engineering or the physical sciences. However, the addition of a new text to an already large accumulation of basic physics books might well be questioned, since a number of excellent texts already exist.

Nevertheless, new books are needed and will continue to be needed, for several reasons. The explosive growth of scientific knowledge and the increasing reliance of engineering technology on basic science and analytical methods make it more urgent than ever that the basic physics course give a thorough grounding in essential principles and associated analytical tools, stripped of gadgetry and lengthy discussions of current technology which will soon grow obsolete. Furthermore, it is essential to raise the level and goals of the introductory course whenever possible, to take fullest advantage of the improved preparation in physics which many high schools now offer as a result of the fine work of the Physical Science Study Committee and similar groups.

This book is intended as an introductory text, elementary yet thorough, which concentrates on fundamentals, uses analytical techniques such as calculus and vector analysis where they are needed, is thoroughly up to date and contemporary in viewpoint, and exhibits the spirit of scientific inquiry and the empirical basis of natural science.

Specifically, this book is intended as the beginning of a series of courses of total length one to two years, starting in the freshman or sophomore college year. For the continuation of the sequence, the other volumes in the McGraw-Hill Series in Fundamentals of Physics are particularly suitable because of their uniformity of level and viewpoint, but there are several other suitable combinations.

As the table of contents shows, the order of topics is not revolutionary. The author believes strongly that physics should be presented as an empirical science and that frequent contact with experience is essential. Thus newtonian mechanics is the most logical place to begin, inasmuch as everyday experience provides an abundance of examples of mechanical principles, more so than for any other branch of physics. Furthermore, the closely knit logical structure of mechanics and its close relations to all the other branches of physics enhance its suitability as a starting point.

The table of contents indicates the scope of the book, but we also wish to point out the following features:

1. The book assumes a concurrent course in differential and integral calculus, and elementary calculus is used wherever necessary. It is not our aim to teach calculus as such, but we recognize that for most students calculus is a new and still somewhat unfamiliar tool; for this reason, some applications of calculus are spelled out in more detail than would ordinarily be necessary, especially in the early chapters of the book. No previous exposure to vector algebra is assumed; a systematic introduction is provided in Chapter 2, and further explanations of various essential points accompany their application to physical situations. As is customary, vector quantities are denoted by boldface symbols; in addition, boldface **+**, **−**, **Σ**, and **=** signs are used in vector equations to denote vector addition and equality.

2. The book attempts to exhibit the inductive and empirical nature of physics along with its deductive aspects. Care has been taken to distinguish clearly between principles which are generalizations from experience and those which are derived, and to indicate the experimental basis of the former. The relative status of each principle in the whole logical structure is thus made clear.

3. Throughout the book the importance of *models* is stressed. We rarely deal directly with physical reality, but rather with simplified models designed to retain the essential features of a physical situation and eliminate the unessential ones, to facilitate analysis. The student is constantly reminded of the process of constructing models as idealizations of reality, and of the limitations of analytical results imposed by the limitations of validity of the model.

4. In the chapters on elementary thermodynamics we abandon completely the classical approach with its confinement to a macroscopic viewpoint. Instead the macroscopic and microscopic approaches are thoroughly interwoven; a common theme in these chapters is the relation between the macroscopic behavior of matter and its microscopic structure. Thus the kinetic-molecular model of an ideal gas is discussed in detail, and its relation to the first law of thermodynamics is exhibited. The concept of entropy is discussed

as a measure of the microscopic disorder of a system as well as a macroscopic thermodynamic quantity.

5. An attempt has been made to exhibit the essential *unity* of various branches of physics; in particular, mechanical principles and the various conservation laws are applied to atomic and nuclear phenomena and to the structure of matter, as well as to problems in macroscopic mechanics. As an aid to understanding the status and relationships of various principles, short Summary and Perspective sections are inserted at intervals of three or four chapters.

6. With a few exceptions, the mks system of units is used exclusively. There seems little doubt that it will eventually be used universally in scientific work. In addition, the author feels strongly that the burden of mastering several systems of units simultaneously should not be added to that of mastering new physical concepts. If the British system of units is needed in later engineering courses, it can easily be learned once the basic principles are well in hand. Several tables for conversion of units, both metric and British, are included in Appendix B.

7. An unusually large collection of almost 600 problems is included. A few of these are simple substitution exercises, designed to illustrate definitions, but most require some thought and insight on the part of the student. A majority of the problems are literal or algebraic rather than numerical; some are too difficult for all except the best students, and there is plenty of material for "honors" sections. In several cases a sequence of problems can be used to explore additional subject matter. For example, Problems 17-4, 18-14, 18-20, 18-21, 18-25, and 19-11 together constitute a brief introduction to the thermodynamics of paramagnetism, a topic which is not discussed explicitly in the text.

This book grew out of the author's experience with the freshman physics course for engineering and science students at Carnegie Institute of Technology, where it is used for the first two semesters of a four-semester sequence, three credit hours each semester. The following two semesters deal with electricity and magnetism, optics, atomic physics, and the structure of matter. A concurrent calculus course accompanies all four semesters. This book is also suitable for the first semester of a two- or three-semester sequence of four or five credit hours each semester; when used for a one-semester course, it may be shortened somewhat. Several sections and a few entire chapters may be omitted without interrupting the continuity.

These include Chapters 13, 14, 19, and 20 and Sections 6-5, 7-4, 7-6, 8-5, 8-6, 9-6, 9-7, 10-5 to 10-7, 12-5, 16-5 to 16-8, 17-4 to 17-6, 18-6, and 18-9. By omitting selected combinations of these sections, courses with a variety of length and emphasis can be constructed.

Although this book is primarily intended as a high-level introductory text, it may also be used for an intermediate course following a first physics course given without calculus. A thorough and detailed exposition of principles and a plentiful supply of challenging problems make it useful for such intermediate courses.

HUGH D. YOUNG

Acknowledgments

This book has benefited greatly from the advice of a number of people. The following have reviewed part or all of a preliminary form of the manuscript: Prof. Stanley Ballard, Dr. Arthur Beiser, Prof. Owen Chamberlain, Prof. Edward Condon, Prof. Arthur Kip, Prof. Hans Mark, and Dr. William Wolfe. Their critical comments and suggestions have been invaluable. The author is also grateful to his colleagues at Carnegie Institute of Technology, whose suggestions have greatly increased the book's usefulness as a teaching tool, and to the two generations of freshmen at Carnegie who mercilessly but constructively pointed out errors and obscure passages in the preliminary editions. Particular thanks are due to the various members of the secretarial staff at Carnegie who aided in the preparation of several successive versions of the manuscript. Finally and most important, the author acknowledges his great debt to his wife Alice for her unending patience, confidence, and moral support throughout the writing of this text.

Introduction

WE ARE LIVING in a period in which great advances are being made in the teaching of physics in elementary schools, in high schools, and in colleges. We are living in a period in which an understanding of physical laws is being increasingly recognized as an essential ingredient not only of a technical education, but also of a liberal education. We are living in a period in which biology and modern medicine as well as engineering are built on quantitative formulations of physics and physical chemistry, so that the old one-year-without-calculus course in physics no longer suffices as an adequate preparation for even the premedical student.

The trend toward a fuller presentation of physics to college students, which is now in full swing, is facilitated by the great improvements which have been made in high school teaching in the last few years, especially with the aid of the projects supported by the National Science Foundation.

Such improvements in teaching, in the selection of material to be taught, and in the books in which the material is presented are based upon recognition of the demands of the explosion in scientific knowledge. In his much-discussed Rede Lecture, Sir Charles Snow describes the impoverished condition of those academic traditionalists who shut their eyes to the great intellectual adventure which mankind has been experiencing through the advance of science:*

> They still like to pretend that the traditional culture is the whole of "culture," as though the natural order didn't exist. As though the exploration of the natural order was of no interest either in its own value or its consequences. As though the scientific edifice of the physical world was not, in its intellectual depth, complexity and articulation, the most beautiful and wonderful collective work of the mind of man. Yet most nonscientists have no conception of that edifice at all. Even if they want to have it, they can't. It is rather as though, over an immense range of intellectual experience, a whole group was tone deaf. Except that this tone-deafness doesn't come by nature, but by training, or rather the absence of training.

* *The Two Cultures and the Scientific Revolution,* Cambridge University Press, 1961, p. 15.

Among the steps needed to cure this ailment, at least in the field of physics, is the training of students in the ways of physicists as well as in physics. The present volume, *Fundamentals of Mechanics and Heat,* by Professor Hugh Young, follows this principle by leading the student through patterns of intuitive and inductive or deductive processes by which physical theories have always been developed. It presents the basic concepts which were developed by Galileo and Newton some three hundred years ago for the description of motion of macroscopic bodies whose behavior can be directly observed. On these principles all of modern physics is founded, even when important modifications are needed to describe motions at great velocity (relativity) or the motion of electrons, protons, and neutrons (quantum mechanics). In some quarters, there is a tendency to rush into the discussion of these topics before the student has a firm grounding in classical mechanics. This is a mistake that Professor Young does not make.

In the latter part of the book the basic concepts for description of thermal phenomena and the interpretation of heat in terms of random molecular motion are carefully developed. The student is soundly introduced to one of the great generalizations of nineteenth-century physics, the Second Law of Thermodynamics, an understanding of which is essential for anyone to be scientifically literate.

The volume is intended as part of a series of which *Fundamentals of Electricity and Magnetism* by Professor Arthur Kip, of the University of California at Berkeley, appeared about two years ago. Although the two books have been planned to be used together, each one is complete in itself.

It was originally intended that this series should consist of four volumes. But further study has shown that a good introduction to modern physics can be provided with a series complete in three volumes. The third volume, which is being prepared, deals with the fundamentals of optics and modern physics.

Taken together, the three volumes provide a sound preparation for further study of physics, or chemistry, or medicine, or engineering; and they provide a clear understanding of the ideas which have, in the past century, transformed the world in which we live.

E. U. CONDON
Professor of Physics and
Fellow of the Joint Institute for Laboratory Astrophysics
University of Colorado, Boulder, Colorado

Contents