MODERN COLLEGE PHYSICS

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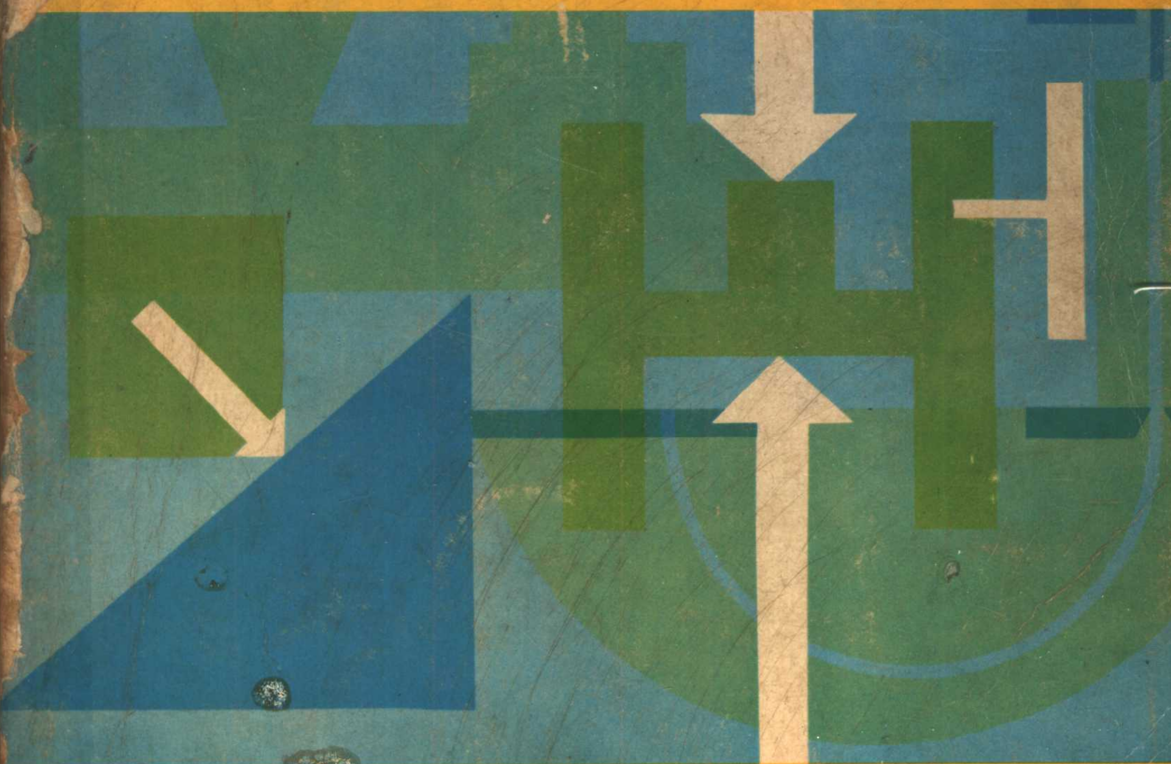

RICHARDS • SEARS • WEHR • ZEMANSKY

MODERN COLLEGE PHYSICS

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ADDISON-WESLEY PUBLISHING COMPANY

Reading, Massachusetts

Amsterdam • London • Manila • Singapore • Sydney • Tok

THIS BOOK IS AN ADDISON-WESLEY
WORLD STUDENT SERIES EDITION

SEVENTH PRINTING 1977

Library of Congress Catalog Card No. 62-11794

PREFACE

This text is both new and old. It is new in that it presents in one volume a course of study which assumes no background in physics but which provides a meaningful introduction to classical, relativistic, and quantum physics. In an ambitious course it can be covered in one year. A background in chemistry is desirable, and a concurrent course in calculus is recommended but not required. Vectors are expressed in boldface type wherever magnitude *and* direction are meant, and both the scalar and vector multiplication operations are introduced. These techniques emphasize vector quantities and permit many physical laws to be presented more concisely.

This text is old in that it is almost entirely taken from two other texts: *College Physics* by Sears and Zemansky and *Introductory Atomic Physics* by Wehr and Richards. Some parts have been rewritten, particularly the discussions of work, energy, and momentum. Considerable material in the source books has been omitted. This shortening has been accomplished for the following reasons. First, there was some material common to both books. Second, most students who use this book will take additional courses which will include topics we have deleted. Third, some topics are applications which will be covered in the laboratory. Fourth, some traditional topics, such as color and musical scales, are of secondary importance to physics, inasmuch as they involve psychology as much as they involve physics. We have retained those topics which provide a foundation in physics and which are essential to a unified development of the subject. Anyone familiar with the source texts will note that those topics we have included here are treated about as extensively as they were in the sources. Although we have shifted the emphasis, we have retained or increased depth of content.

Both the English and metric systems of units have been introduced and used. The meter-kilogram-second system is used throughout, and the English engineering system is used for topics where engineers use them. We have introduced special units like the electron volt and the angstrom where these units are essential to the subject matter.

We gratefully reaffirm our thanks to the many students, colleagues, and friends whose comments and suggestions concerning the source books are reflected in *Modern College Physics*. Particular thanks are extended to R. A. Boyer, L. C. Heckert, R. A. Kane, P. Kirkpatrick, and M. C. Schwartz.

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Philadelphia, Hanover, and New York
January, 1962

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CHAPTER 1

COMPOSITION AND RESOLUTION OF VECTORS

1-1 Introduction. A good mystery story is a kind of game. The author describes a situation—usually violent. The detective inquires into the activities of the principal characters and conducts an investigation, during which various facts are brought out. You, as the reader, try to organize these clues by framing hypotheses which will "explain" the facts. When more information becomes available you may have to revise your hypotheses as they become inconsistent with new facts. A clever author of a good mystery may fool you into several blind alleys before the detective finally resolves the whole matter in an intellectually satisfying way. You remember the clues which set him on the right track and you realize that if you had been as observant as he you would have come to the heart of the matter as quickly as he did.

Scientific investigation is very much like a good mystery story which has no apparent end. Some hypotheses about the universe seem ridiculous today. Ptolemy taught that the earth was the center of the solar system, with the sun and all the planets moving about it in complicated paths. Copernicus, on the other hand, adopted the view that the earth and the other planets revolve about the sun. Only about a hundred years ago there was supposed to be a substance called *caloric* which accounted for an astonishing number of phenomena but which was specifically designed to account for the changed properties of bodies as they are heated and cooled. Heat was considered to *be* caloric, and when a body was heated the caloric entered the body and caused it to expand. Although we now have no need whatsoever for this concept, it still lingers on. We still speak of heat "flow" as though heat were a fluid. We could enumerate similar abandoned hypotheses almost without limit.

Some of the blind alleys into which science has turned have seriously delayed progress. On the other hand, some alleys which seemed to be "dead end" have been far from blind. The alchemists tried to change lead into gold. Their efforts were frustrated, but they discovered many less profound changes which were nevertheless important. They were the first chemists. At the beginning of this century it was thought that light was a wave motion of a substance called the ether. This theory has been abandoned in the sense that we know that we have a better one (which we will discuss later in this book). But the wave theory of light has by no means been abandoned as a means for understanding many phenomena. The wave theory has so much "truth" about it that it is still exceedingly useful. It approximates the truth very, very closely in many situations. It was a fruitful theory because it correlated a tremendous range of observations and suggested possibilities previously unanticipated, and even though it has been modified, it is still useful and worthy of detailed study.

One might suppose that we could convey the latest ideas about physical reality with a minimum of wasted effort by skipping theories which have been discarded or modified, and instead beginning with the most modern interpretation of physical events. There are several reasons why we must begin with the older classical physics. The familiar languages of words and pictures are sufficient for introducing classical physics but they cannot adequately portray modern theories. The elegant language of modern physics is higher mathematics, since the modern concepts are impossible to visualize. One might begin with modern physics for a group of trained mathematicians, although it would be hard to find such a group which did not include many who had studied classical physics as part of their training. Fortunately, it is possible to convey much of the new physics if, in addition to words and pictures, there are classical concepts to enlarge and modify. A more practical reason for starting with classical physics is that despite its having been replaced theoretically, it is still an extremely useful approximation. It is relatively simple and it is precise enough for the solution of many problems in science and engineering. A third reason is that classical physics came before modern physics. Our treatment is hardly chronological, but we do trace, however loosely, the development of ideas. It spoils a mystery story to read the last page first.

Thus our telling of the "mystery story" of physics will include some ideas which we will later replace with new ideas that are more inclusive or more exact. Since the mystery of physics has no apparent end, the best modern ideas may become old in their turn. One thing, however, is certain. The scientists who devise the theories of tomorrow will be thoroughly familiar with the theories of today.

In order that the "clues" we present may be quantitative, we begin by discussing measurements.

1–2 The fundamental indefinables of mechanics. Physics has been called the science of measurement. To quote from Lord Kelvin (1824–1907), "I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of *Science*, whatever the matter may be."

A definition of a quantity in physics must provide a set of rules for calculating it in terms of other quantities that can be measured. Thus, when momentum is defined as the product of "mass" and "velocity," the rule for calculating momentum is contained within the definition, and all that is necessary is to know how to measure mass and velocity. The definition of velocity is given in terms of length and time, but there are no simpler or more fundamental quantities in terms of which length and time may be expressed. *Length and time are two of the indefinables of mechanics.* It has been found possible to express all the quantities of mechanics in terms of only three indefinables. The third may be taken to be "mass" or "force" with equal justification. *We shall choose mass as the third indefinable of mechanics.*

In geometry, the fundamental indefinable is the "point." The geometer asks his disciple to build any picture of a point in his mind, provided the picture is consistent with what the geometer *says* about the point. In physics, the situation is not so subtle. Physicists from all over the world have international committees at whose meetings the rules of measurement of the indefinables are adopted. The rule for measuring an indefinable takes the place of a definition.

1-3 Standards and units. The set of rules for measuring the indefinables of mechanics is determined by an international committee called the *General Conference on Weights and Measures*, to which all the major countries send delegates. One of the chief functions of the Conference is to decide on a standard for each indefinable. A standard may be an actual object, in which case its main characteristic must be *durability*. Thus in 1889 when the meter bar of platinum-iridium alloy was chosen as the standard of length, it was felt that this alloy was particularly stable in its chemical structure. If, instead of platinum-iridium, a glass bar had been chosen, its length would have changed throughout the years because of the unavoidable crystallization that glass undergoes as it ages. Although platinum-iridium is an unusually stable alloy, the preservation of a bar of this material as a world standard entails a number of cumbersome provisions, such as making a large number of replicas for all the major countries and comparing these replicas with the world standard at periodic intervals.

On October 14, 1960, the General Conference changed the standard of length to an *atomic constant*, namely, the *wavelength of the orange-red light emitted by the individual atoms of krypton-86* in a tube filled with krypton gas in which an electrical discharge is maintained. The standard of mass is the mass of a *cylinder of platinum-iridium*, designated as *one kilogram*, and kept at the International Bureau of Weights and Measures at Sèvres, near Paris. Before 1960, the standard of time was the time between successive appearances of the sun overhead, averaged over a year, known as a mean solar day. This has now been changed to what is