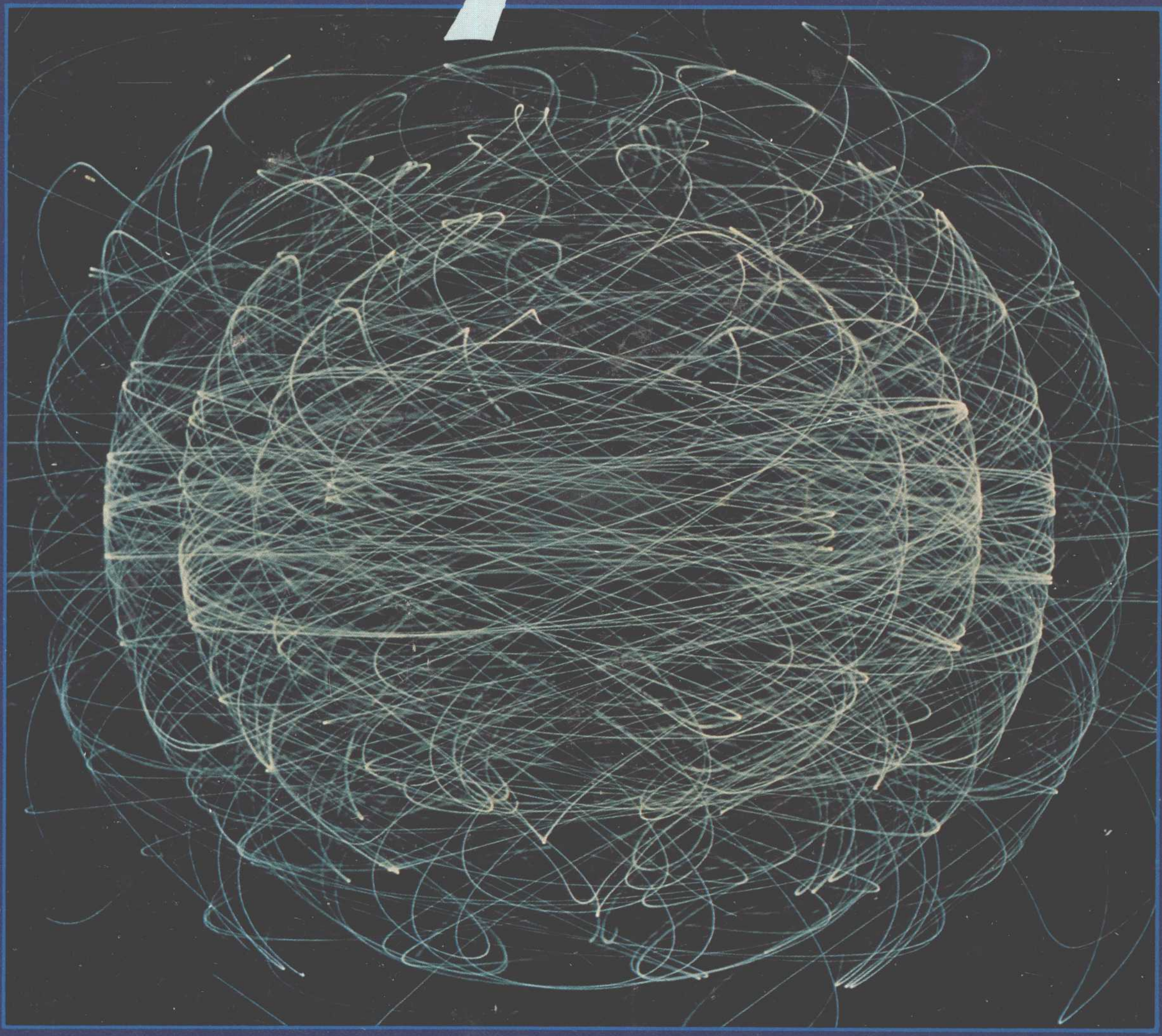
PRINCIPLES OF
Physics



Marion & Hornyak

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Physics

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PREFACE

This is a text for an introductory physics course for students of science and engineering. It is intended for courses requiring calculus either as a prerequisite or as a corequisite. It is ideally suited to courses covering topics in classical physics in two semesters. Its more elaborate companion text, *Physics for Science and Engineering,* is directed to courses that allow ample time to explore many topics in great depth. This text, however, is no simple abridgment of the longer companion. To fit the shorter course schedules a careful selection of subject matter was made, restricting treatment to a smaller number of essential topics.

In this text, many sections appearing in the companion work are rewritten and rearranged. The following are examples of major changes. The chapters on rotation of rigid bodies and dynamics of rigid bodies are now combined into a single chapter restricted to only the simplest types of rotational motion, that about a fixed axis and rolling motion. The chapter on deformation of solids has been eliminated. The chapters on static fluids and fluid dynamics have been condensed into one chapter that appears earlier in the text; this allows the chapters on oscillatory motion, mechanical waves, and sound to be placed together. The chapters on electromagnetic waves and radiating systems have been combined into a shorter single chapter. The chapters on geometric optics and optical instruments have likewise been combined, shortened, and placed after the chapters on interference and diffraction.

Opting for a less encyclopedic treatment still allows the selected topics to be developed in adequate detail for solid understanding. We continue the style of the companion text, which is informal but at the same time is concise and crisp and has a no-nonsense character.

A hallmark of this text is again the realistic treatment of topics. For example, the sliding contact between smooth surfaces is *not* taken as synonymous with the absence of friction; quite the contrary is shown to be the case. The examples cited in most texts as applications of Bernoulli's equation are really invalid, since they seldom involve laminar flow; instead, as it should be, the energy equation for fluid flow is cited here. The rather accurate predictions based on the application of the ideal gas law to simple real gases (such as air at near normal conditions of temperature and pressure) is *not* due to the absence of short-range intermolecular phenomena, but is shown rather to be due to the fortuitous cancellation of opposing effects. As a general policy, the approximations necessary for a first order treatment of any phenomenon are clearly spelled out.

Mathematics. Advanced mathematical tools are introduced ''gently,'' and the need for their use is motivated in each case by the subject at hand. If calculus is begun as a corequisite, this approach also allows the mathematics course to catch up its use in physics. Even when the first course in calculus is a prerequisite, some students may benefit from this ''need-to-know'' approach.

Differentiation is introduced as a logical requirement for a more precise understanding of motion. The concept of work is used to introduce the dot product of vectors and the definite integral. The cross product of vectors is first met in the chapter on angular momentum. Integration along specific physical paths appears only in the most elementary context: in discussing work, thermodynamic processes, Ampère's law, and electromagnetic induction. Simple surface integration is introduced in connection with Gauss's law. Geometric symmetry is often used in the examples in order to reduce normally required multiple integration to one or more simple single integrations.

Optional Topics. This text contains three different types of optional material. There are ''extended footnotes'' in the body of the text (in smaller type and set off by triangle symbols). There are a few sections labelled *Optional* (generally at the end of a chapter). Any or all of these may be omitted without loss of continuity in later chapters. Finally, we have included three Enrichment Topics at the end of the text. These sections cover applications of general engineering importance (Practical Magnetic Materials) and topics of current interest (General Planetary Orbits and the Electric Dipole Antenna).

Examples, Questions, and Problems. We place strong emphasis on problem-solving ability. Indeed, we view the ability to solve problems as the best proof of a student's understanding of the text material. To achieve this aim, a large number of worked-out examples are presented. The examples span all levels of difficulty, and in each instance situations are selected that emphasize the text presentation. An effort has been made to relate the examples to one another in order to reveal different aspects of a given physical system.

We have sprinkled the text liberally with thought-provoking questions addressed to the student (within parentheses and marked with a small circle •). At the end of each chapter we have also included a set of more elaborate questions.

There are many problems at the end of each chapter, grouped together by section number. Moderately difficult problems are marked with a dot (•) and more difficult ones with two dots (••). Usually there is also a set called Additional Problems, which draws together concepts developed in several sections and may include a few problems of greater difficulty. The answers to approximately half of the numerical problems appear in the back of the book. We use SI units (sometimes referred to as metric or MKSA units) throughout the text, and conversions to other familiar units are mentioned when appropriate.

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Jerry B. Marion
William F. Hornyak

IN MEMORIAM

It is with great sorrow that we note the untimely death of Jerry B. Marion. As his coauthor and friend, I join the physics community in giving tribute and praise for his many contributions to the successful teaching of physics. Sadly, he was unable to see this printed version of the manuscript he so diligently labored over.

W.F.H.

CONTENTS OVERVIEW

CONTENTS

CHAPTER 1

INTRODUCTION

The word *physics* is derived from the Greek word *φῡσις*, meaning "nature." Indeed, physics is a branch of natural science that deals with the properties and interactions of matter and radiation. Because physics is concerned with such fundamental ideas as these, it is generally considered to be the most basic of all the sciences.

The key to progress in the understanding of Nature is to base conclusions on the results of *observations* and *experiments,* analyzed by *logic* and *reason*. This basic approach to science is called the *scientific method*. This "method" is not a prescription for learning scientific truth; instead, the scientific method represents a philosophy of discovery that emphasizes the importance of *measurement* when dealing with problems of the real physical world. Theories are valuable (indeed, indispensable) in organizing the facts that have been gathered about the behavior of Nature. But at its roots, physics is an experimental science. The ultimate answer to any question concerning natural phenomena must be the result of experimental measurement.

In order to describe the natural universe, we use *concepts, theories, models,* and *laws*. Generally, a *theory* attempts to explain why Nature behaves as it does. Paradoxically, to construct a theory, we introduce certain *unexplained* fundamental abstractions or *concepts*. Thus, we consider the concepts of *energy, time, space,* and *electric charge* as "given," without offering an explanation for their existence. (Even so, we can still provide precise *definitions* for these concepts viewed as quantities.) The theory then asserts a connection between these concepts and some observed characteristics of interactions of matter. This connection is achieved by constructing a *model* to reflect the experimentally determined facts. Finally, the deductions from these models result in the *laws* of physics, which tell us *how* things behave in terms of the theory.

How are theories to be judged? If there are several contending theories relating to the same set of experimental facts, how do we decide which to adopt? There are three criteria for answering such questions—*predictive power, comprehensiveness,* and *simplicity*.

A theory, if it is to have merit, must be able to predict observable results of experiments that have not yet been performed. When the experiments *are* performed, the results must agree with the predictions of the theory within acceptable limits. Also, a greater degree of credence is associated with a theory that can relate to a wide variety of phenomena. Finally, we have a faith that Nature is inherently simple, so we are led to believe that a valid theory should be transparent, direct, and simple, with an economy of postulates and ad hoc assumptions. However, simplicity must not be equated with ease of comprehension. The theory of relativity is a model of simplicity and logical precision, based on only two fundamental postulates. But to comprehend fully the implications of this theory is a formidable task.

What is accomplished by constructing a theory? What does a theory really explain? The best answer is probably that our theories provide a point of view of Nature that permits us to assemble in a comprehensible form the essence of a variety of related facts and observations concerning physical phenomena. Theories provide a means of reducing an enormous number of experimental results to a manageable number of precise statements. Progress consists of refining these theories and discovering links among them as new observational information becomes available and as new insights are developed. No theory is perfect, and none is all-encompassing. But we are confident in the expectation that our theories will provide ever better descriptions of Nature through continual evolution.

1–1 UNITS AND STANDARDS OF MEASURE

To describe physical quantities and processes in a precise and orderly way, it is essential that a system of measure first be established. The *units* for quantities such as length, time, and mass must be defined, and standards for these units must be provided so that we can agree on the meaning of measurements. A measurement of some observable can then be quoted as a *numerical value* together with the appropriate *unit* for that quantity. We stress the necessity for developing the habit of *always* quoting physical quantities in terms of a numerical value and the *relevant unit of measure*. It makes no sense, for example, to quote a length as ''60,'' for there is a considerable difference whether the units are centimeters or miles!

Most scientific measurements and most of the world's commerce are carried out in *metric* units. Engineering practice in this country uses the metric system more and more, and there is even a slow conversion to metric usage in the public sector. Within a matter of years the United States may join the rest of the industrialized world in the exclusive use of the metric system.

The metric unit of length is the *meter* (m), originally defined as 10^{-7} of the distance from the Equator to the North Pole along a meridian passing through Paris. This ingenious but impractical standard was replaced in 1889 by the distance between two finely drawn,

The conversion to metric units is taking place in stadiums around the country. (Courtesy of the Philadelphia Phillies. Photo by Paul H. Roedig.)