Physics

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Cover: The beam of light from a metal-vapor laser dispersed into its constituent colors by a diffraction grating. (*Photo by Fritz Goro*)

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Preface

This book grew out of my experience teaching the standard calculus-based physics course at the University of Colorado. Though many of the students had a previous calculus course, calculus was not a prequisite but rather a corequisite requirement. It was tempting to blame insufficiencies of some students upon their lack of a previous calculus course, but this did not seem to be the case. Instead, the most frequent difficulty of the beginning students was an inability to describe an everyday setting in the analytical language of physics, and to project that language back into their reality. Alternatively put, translation from the English language into the language of mathematics, and the inverse process, is a skill which most beginning physics students lack.

The transition from "hunting for a formula which gives the answer," to a reasoning approach that draws upon several facets of knowledge is probably the most difficult step in the development of a physics student. If new ideas are presented too rapidly this transition often is not made at all by the average student. Even a simple notational change, e.g. the dot product, is another fact to be absorbed and digested and can be a distraction. Accordingly, I have tried to pace reasonably the introduction of new concepts. I have also tried to explain more of the reasoning behind many concepts because my students appear to profit from this kind of help.

I have encouraged students to draw sketches and to use mathematical reasoning by example and by explicit direction and discussion. Each new block of material is followed by simple exercises which can be solved readily. These exercises help the student retain the basic ideas and calculational steps utilized in discussing a given phenomenon. When the student is then asked to combine several ideas he is better prepared to do so.

Since many of my students are more interested in dynamics rather than statics, I have begun the text with a discussion of motion and Newton's laws of motion. The concept of momentum is used in a fundamental way and both the differential and integral form of Newton's second law are discussed immediately. The early introduction of calculus does not seem to be a special source of difficulty since most calculus courses are still stressing foundations of calculus at the time a parallel physics course with *any* ordering of topics has need for differentiation and integration. To aid the student enrolled in a corequisite calculus course I have included some math where appropriate. In fact, Chapter Two is a brief introduction to calculus in the setting of kinematics. Mathematical topics are subsequently discussed as they are needed. They are not discussed in a general way, as they would be in a mathematics course, but only in the limited context required in our coverage of physics. This not only serves to prevent overburdening the student with too much knowledge too quickly, but also frequently helps the student who later encounters the same topics in all their appropriate generality in a mathematics course. Most of this supplemental mathematical material is arranged so that it can be deleted by the well-prepared reader.

The first half of the book is taken up with mechanics and thermodynamics. The second half begins with wave motion and leads directly into light as an example of a wave phenomenon. Physical and geometrical optics are discussed. Electricity and magnetism then follow, including a chapter which deals with Maxwell's prediction of electromagnetic waves and the inclusion of light waves in this phenomenon. The final chapter introduces the student to quantum physics. It is historical in its organization and emphasizes wave-particle duality. The overwhelming emphasis of the book is on classical physics, but underlying atomic phenomena are discussed wherever they are appropriate.

In recent years introductory physics courses have concentrated on a physicist's view of physics rather than that of the *user* of physics. Thus, topics such as musical scales, motors, alternating-current circuits and optical instruments have been dropped or de-emphasized by some texts. I have tried to steer a middle course, including those topics which seemed of interest or value to many of the variety of students encountered in introductory physics.

The International System of Units (SI) is the primary system utilized in this book. However, the wide variety of units encountered in *applications* of basic physics tends to put off the student who has never made conversions from one set of units to another. Further, it is still true that most readers have a better mental image of the foot, pound, quart and mile than of their SI analogs. Accordingly, some use is made of English units in early sections of the book. Other units are mentioned and occasionally used in examples when their use seems appropriate, but SI units are emphasized throughout.

I am indebted to many people for their help during the preparation of this book. John Taylor deserves very special thanks for his thorough and constructive criticism after teaching from the entirety of the mimeographed notes. Many other colleagues at the University of Colorado have helped with discussion and William Campbell helped by teaching from the first half of the notes at the University of Nebraska. David Cannell of the University of California, Santa Barbara, Dorothy Wollum of California State, Fullerton, and Jack Wollum of California State, Los Angeles all provided valuable suggestions. Helpful comments were also given by Haywood Blum of Drexel University, Lowell Wood of the University of Houston and Thomas Erber of the Illinois Institute of Technology. Several students have made useful comments and suggestions, most notably Molly Rothenberg, Mark Utlaut and Larry Zanetti; and many have offered encouragement. Several fine photographs (those not otherwise credited) resulted from the joint efforts of John Groft and Robert Stoller. George Thomsen's early support and persistent encouragement were most welcome. Finally, for the typing and proofreading of endless chapters and revisions, and for her constant support, I thank my wife Joellen.

Chris D. Zafiratos
February 1975

About the Author

Chris Zafiratos is a Professor of Physics at the University of Colorado. He received his B.S. at Lewis and Clark College in 1957 and his Ph.D. at the University of Washington in 1962. He continued with post-doctoral research in Nuclear Physics at the Los Alamos Scientific Laboratory and taught at Oregon State University before coming to the University of Colorado in 1966. He is a member of the American Physical Society and publishes research articles in experimental nuclear physics. He has been involved with the evolution of introductory physics courses at the University of Colorado and currently (1974–76) serves as chairman of the Nuclear Physics Laboratory of the University of Colorado.

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Chapter 1

Introduction

1-1 The Content of Physics Many of the physical sciences imply their content in their name: astronomy, biology, and oceanography are examples. Physics, however, does not. Indeed, the subject matter of physics is so broad that it underlies and runs through all of the physical sciences. Because of the tremendous revolutions in relativity and quantum physics that occurred around 1900, it is convenient to divide physics into classical physics (pre-1900) and modern physics. Some topics included in these two areas of physics are tabulated below.

TABLE 1-1 Some Topics of Classical and Modern Physics

Classical Physics	Modern Physics
Mechanics	Quantum mechanics
Gravitation	Relativity
Heat	Atoms
Sound	Nuclei
Light	Elementary particles
Electricity	Condensed matter
Magnetism	

Mechanics is the name given to the theory of motion. It gives a precise relationship between motion and the forces that cause it. By the beginning of this century it was already clear that heat and sound phenomena could be understood in the framework of classical mechanics, the mechanics originated by Newton in the seventeenth century. It was also clear that electricity and magnetism formed a unified topic and, further, that light was simply an electromagnetic wave. The physicist of the 1890s had every reason to be smug. The way in which electric charges moved could be understood by combining electricity and magnetism with mechanics, and the way in which planets and stars moved could be understood by combining gravitation and mechanics. Since matter is composed of atoms, which themselves contain electric charges and gravitating mass, complete understanding of the physical universe seemed at hand.

Unfortunately, classical mechanics failed badly when it was applied to the internal motion of atoms. As an example of the magnitude of the failure, consider the lifetime of isolated atoms. Classical physics predicts that such atoms will collapse in 10^{-8} seconds, yet atoms are known to be perfectly stable for periods of time enormously longer than that.

Over a period of years, culminating in the 1930s, the new theory of quantum mechanics was developed. It dealt, correctly, with questions of atomic and subatomic motion and structure. It also showed that the older classical physics was correct for objects much larger than atoms, as long as the velocities involved were much smaller than that of light.

For motion involving velocities near that of light (3×10^8 meters/second), classical mechanics fails even for objects much larger than atomic dimensions. Einstein's *special theory of relativity* leads to a *relativistic mechanics* that is part of modern physics and that can cope with all possible velocities. Einstein's *general theory of relativity* replaces Newton's classical theory of gravitation. General relativity is required, for example, to understand the gravitational effects of ultradense stars, which are currently of great interest in astronomy. However, for the sort of densities and velocities encountered in our solar system, classical gravitational theory is for the most part sufficient.

Most of the phenomena of an everyday nature and a good many of those encountered in modern technology can be understood most simply and elegantly with the aid of classical physics. Furthermore, the groundwork covered in a study of classical physics is required in any thorough study of modern physics. Some ideas of modern physics will be touched upon in this text but we will concentrate heavily upon classical physics.

Having briefly described the major topics of physics and the portion covered in this text, we ask, what about the work carried on by the contemporary physicist? A good many physicists, along with their colleagues in engineering, are occupied with applications of physical knowledge for benefit of consumers, corporations, governments, etc. These physicists collectively utilize the full range of classical and modern knowledge. Obviously a good many physicists teach physics. Finally, many contemporary physicists pursue basic research aimed at the unanswered questions of physics. Of course, many individual physicists fall into more than one category. We can obtain some idea of the unanswered questions that attract the attention of research physicists by listing the major categories of the papers that are published in current research journals.

TABLE 1-2 Major Categories in Current Physics Journals

Atoms, molecules and related topics
Condensed matter (solids and fluids)
Electromagnetic, gravitational, and quantum fields
Elementary particles
Nuclear reactions and nuclear structure
Quantum mechanics
Statistical mechanics and thermodynamics

What may be the most important modern development in science is perhaps too close in time to be clearly recognized. This development is the wide-ranging unification of all the physical sciences, including engineering and biology. This unification is an ongoing process that has enormous benefits in increasing our intellectual power with an economy of required basic concepts. The contemporary physicist finds more and more of the language and methods his predecessors developed appearing in all the physical sciences. The increasing unity in the panorama of the sciences may be a reflection of a basically simple and unified universe. Or we may be in for a rude awakening in the near future. In any event, these are lively times for the intellectually curious person.

1-2 The Fundamental Quantities of Mechanics

Many quantities enter into mechanics: speed, force, mass, acceleration, length, time, direction, and weight are examples that come to mind. Most of the above quantities can be defined in terms of one another. Speed, for example, is simply the ratio of the distance covered (a length) to the time required to do so. However, a certain