JAY OREAR

SECOND EDITION

FUNDAMENTAL PHYSICS

Fundamental Physics

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Jay Orear

PROFESSOR OF PHYSICS, CORNELL UNIVERSITY

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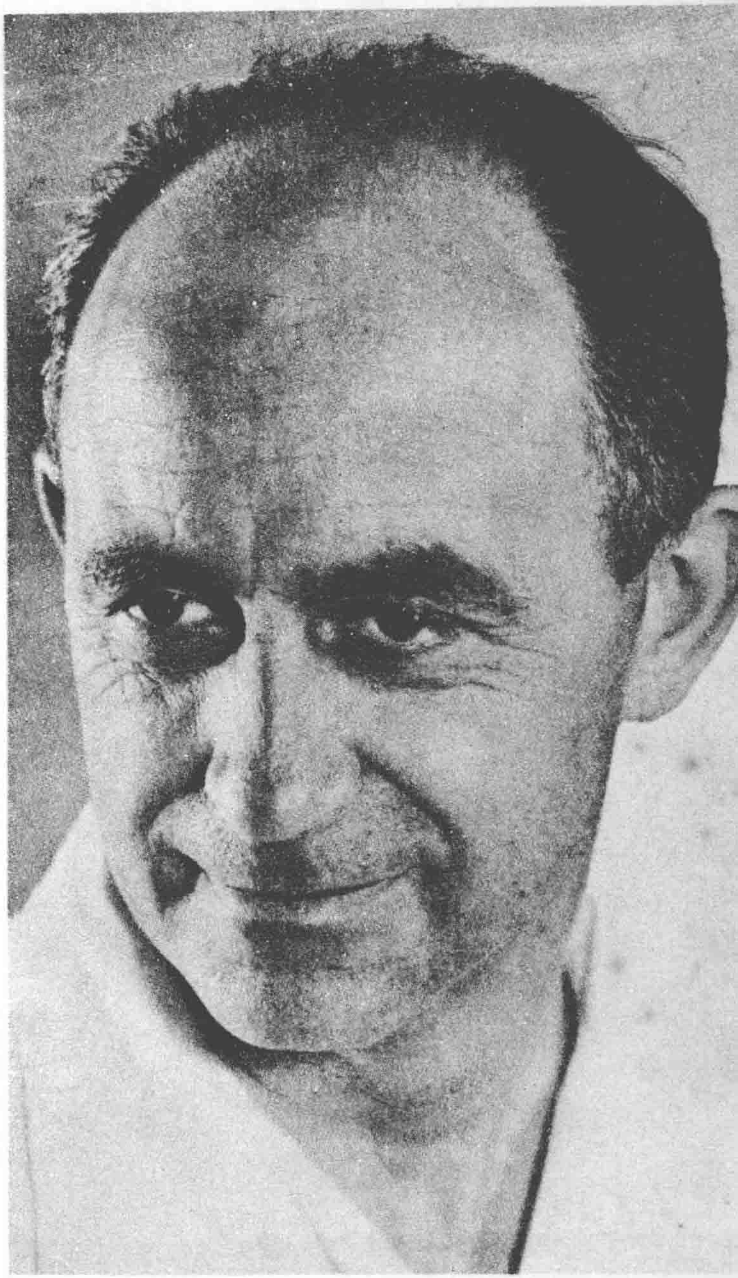

Enrico Fermi, 1901-1954

Note to the student

This book contains a new feature which is a kind of built-in "teaching machine". At the bottom of each page (whenever there is room) is a "test your understanding" question, and on the next page is the answer. To gain the full value from these page-by-page questions, the reader should stop and answer each one before going on or looking at the answer. These questions are relatively easy and many of them can be answered without using paper and pencil. Whenever one of these questions is missed, it is probably because the reader did not understand fully what he had just finished reading. This is a common problem in the study of physics. It can be easy to read, but the understanding requires more than reading or rote learning—it requires thought, and there is no easy way to avoid the necessary thought. So if you miss one of these questions, let it be a warning that you should not go ahead without another reading and thinking through of that section. Remember, we become wise only when we are fully aware of what we do not understand.

Further help of this nature can be obtained from the *Programmed Manual for Students of Fundamental Physics* also published by John Wiley & Sons, Inc. This is a teaching machine in the form of a programmed manual which covers more thoroughly nearly all the material of the textbook.

Preface to second edition

This second edition is not the kind of revision in which the problems are renumbered and the physics brought up to date by adding a few pages at the end. It is a serious attempt to rewrite the entire book in order to increase the amount of explanation without much increase in subject matter. Few new concepts have been added; there are, however, many more examples, figures, and problems. Over 100 of the illustrations and about 100 of the problems are new. Many of the new examples and explanations are based on five years of feedback from students and teachers. Other sources are the *Programmed Student Manual* and conferences and study groups sponsored by the Commission on College Physics.

A major innovation is the thorough and unified treatment of quantum mechanics running through Chapters 12 to 16. I think of these chapters as a serious introductory course in quantum mechanics at the pre-calculus mathematical level. I know of no other introductory physics text at this level which develops the concepts and applications of quantum mechanics so thoroughly and so quantitatively, and I am convinced that a surprising amount of quantum mechanics can be taught without calculus. In most of the situations in physics in which both calculus and noncalculus explanations exist, I prefer the noncalculus explanation—even for erudite graduate students. The noncalculus explanation usually gives more physical insight and is easier to visualize.

It has been my experience that college freshmen can master some of the basic concepts of quantum mechanics as well as special relativity, and that they derive special enjoyment and excitement from these subjects. Consequently, even more emphasis is placed on quantum mechanics and relativity in this revised edition. Perhaps this is the new trend—these subjects are now taken seriously in a few of the more recent introductory textbooks. But I believe this book gives a more "grown-up" quantum mechanical explanation of atomic structure, theory of metals, nuclear structure, diffraction scattering, semiconductors, hybridization, lasers, radioactivity, etc. Other features of the new edition are a quantitative treatment of cosmology and Mach's principle, and the relativistic foundation of magnetic force.

Back in 1960 when the first edition was published, it was considered daring to involve an introductory course so deeply with relativity, quantum mechanics, and its applications to atomic, solid state, nuclear, and high energy physics. Other innovations of the first edition were the format, the use of two colors throughout, extensive use of bubble chamber photos, quantitative drawings of electron clouds, Gaussian units in electricity, and a "cheat-proof" programmed students manual. Since then new books have appeared from the high school level on up incorporating some of the above innovations. Additional subject matter pioneering has been done in connection with the recent Cal Tech and Berkeley introductory courses for physics majors. I have found some of this new material appropriate for nonscience majors and have incorporated it with suitable modifications in this new edition.

A new feature starting with this edition is a kind of page-by-page built-in teaching machine. Experience with the Programmed Manual which accompanies this text has pointed out that one of its major advantages is to let the student know whether or not he really understood what he just got through reading in the text. It takes an exceptionally wise person to know just what he does and does not understand. Students should be urged to answer the questions at the bottom of each page as they come to them before looking at the answers.

In this new edition a serious attempt has been made to keep up-to-date with the exponentially increasing advance of science. I must confess that physics has progressed farther in the last six years than I had anticipated. The pace seems to increase with time. Take for example the number of elementary particles. When the first edition was completed the number of elementary particles had appeared to settle down to 30. But in the past five years the number has increased from 30 to about 200 with no end in sight. Fortunately the newly discovered particles have revealed new patterns or symmetries which make even the original 30 easier to understand. But then recent violations have been found of other more cherished symmetries or conservation laws which should have been obeyed by the elementary particles. These and other new developments such as quasars and lasers have been incorporated into whatever spot in the book is most appropriate. Even the classical physics in this book is "modern". All the physics is put in the context of 1966, not 1900 as most books, or 1925 as in some of the so-called modern physics books.

I am grateful to students, teaching assistants, and faculty at Cornell University for much of the new material. I wish to thank in particular Professors Alan Bearden, Robert Sproull, Phil Morrison, and R. Rajaraman. I also wish to acknowledge stimulating discussions with Professor Matt Sands concerning the new Cal Tech course developed by Feynman, Leighton, and Sands which cannot help but influence future physics textbook writers.

Jay Orear

September 1966

Preface to first edition

Just what is physical reality? What makes the universe tick? What are the "secrets" of nature? These questions exemplify the spirit and motivation of this book. It is primarily designed for use as a text in a one-year course at the college level for students who have had little previous training in mathematics and science, but it should also be helpful to science majors learning college physics for the first time.

In this textbook the main emphasis is on the first principles or fundamental laws of nature upon which all science is based. This area of study is properly a part of the vast collection of topics called physics. Thus this is another college physics textbook, but it deals lightly with the topics of more applied nature which are traditionally also called physics. For example, little will be said about machines, rotational dynamics, photometry, optical instruments, a-c theory, calorimetry, elasticity, acoustics, etc. By restricting the book to "fundamental physics" as opposed to "applied physics" there will be fewer topics, with the accompanying advantage that they can now be treated with greater depth. The main exception to this rule is Chapter 10 which goes deeply enough into electronics to explain the basic principles of radio and television in order to give a feeling for the vast technological implications of our understanding of the basic laws of nature. This chapter may be skipped by those who dislike teaching engineering in a physics course.

By its very nature, fundamental physics is deeply philosophical. It is a continual struggle of man's mind against nature, with nature full of shocking surprises to which man must then adjust. There is a temptation to present this battle of man's mind vs. nature to the liberal arts student using a philosophical and historical approach. Such an approach often makes the mistake of teaching about science rather than teaching the science itself, leaving the student without any real understanding of the physical world in which he lives. The "educated man" should be exposed to both approaches. Ideally he should learn about science and its relation to the other disciplines in his philosophy courses. On the other hand, there is no harm in presenting some of this "humanistic approach" in the introductory physics course as long as primary emphasis is placed on the teaching of the science itself. Consequently, this book gives some attention to the impact of science on our culture. The methods of science, the "art" of scientific discovery, the social responsibility of scientists, along with philosophical, social, and political relations of science to our culture are discussed, but they play a secondary role to presenting the subject matter of the science itself. The excitement and cultural value of the history of physics are made use of where appropriate to the main goal. The acid test of whether a student has grasped science itself is whether he can successfully solve problems that require some thought. My experience with much of the material and problems in this book in college courses at Columbia and Cornell Universities indicates that it is possible for nonscience liberal arts students to master the fundamental principles as evidenced by their ability to apply them in problem solving.

The order of presentation is mainly determined by what I feel to be pedagogically preferable. This tends toward development of logical sequences. Sometimes the "modern" physics manages to get presented before the "classical" and "preclassical" versions are discussed. Usually I have attempted to avoid the sequence: teach a topic according to the "old" physics, tell the student it is now wrong, then try to get the student to unlearn it and relearn it the new way. When a new topic is encountered, the final version is usually given first. Then from this viewpoint the student can observe and understand more fully the various "old" ideas. The sequence of topics was not determined by tradition, but by the requirements of a rather tight logical development. For example, the general phenomenon of barrier penetration is first introduced in the text in a discussion on field emission of electrons from a metal. This discussion depends on the previous presentations of Fermi energy, metallic binding, and potential diagrams, which depend in turn on the presentations of electron waves in a box, atomic electron clouds, and electric potential. Going back further in the logical chain of development are wave-particle duality, wave interference, electricity, energy, mechanics, etc. Hence most of the pages of this book belong to a central chain of logical development. Because of the compact, unified, theoretical structure of physics, my chapters do not correspond to the old, compartmentalized series of "independent" topics found in traditional textbooks. I was unable to tie the chapters up into neat, self-contained, airtight packages. To present classical physics in such a manner may be easier and more satisfying to some, but that just is not the way nature happens to be. I have attempted to present the true product: the imperfections and limitations of present-day physics are openly admitted.

I have also tried to face up to the fact that our present-day description of most physical phenomena requires use of the quantum theory. With the recent development of quantum electrodynamics enormous progress has been made in our understanding of the physical world and the structure of matter. If at all possible, students at the college level should be given a glimpse of our present understanding. Some physics teachers may feel that such topics as electron clouds, quantum theory of chemical binding, Fermi energy, time dilation, nuclear structure, cosmology, and conservation of parity are too difficult and abstract for college freshmen. However, it has been my experience in teaching this kind of course for the last six years that liberal arts students have more trouble in understanding Newton's Third Law than they do in understanding Fermi energy or charge conjugation invariance. Not only do they finish the course with a good physical feeling for modern physics, but they also express a strong preference for it over classical physics.

In conclusion, I wish to thank my colleagues at Cornell for their encouragement and particularly Professors Robert Sproull, Phillip Morrison, John DeWire, and Richard Feynman for their many helpful suggestions. Many people kindly contributed visual material for this book which would have been impossible for any one man to produce. I have drawn upon the visual material of the Physical Science Study Committee of Educational Services, Inc. and am grateful to them and Professor Francis Friedman

for their help and cooperation. Mr. Kim Choy of Cornell was of considerable help in calculating the hydrogen electron clouds and the deuterium nuclear cloud. I am grateful to Mr. Francis Schrag and the many other students who contributed a great deal to the preliminary edition of this textbook while in use at Cornell for the last two years.

My greatest debt is to Enrico Fermi, who not only taught me much of the physics I know, but also how to approach it. As a teacher, Fermi was well known for his great ability to make the most difficult topics seem beautifully simple in a clear, direct way with little mathematics, but much physical insight. The goal I have been aiming at is to try to present the spirit and excitement of physics in the way that Fermi might have done.

Jay Orear

September 1960

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* May be omitted in a fast paced or shorter course.

Introduction

Chapter 1