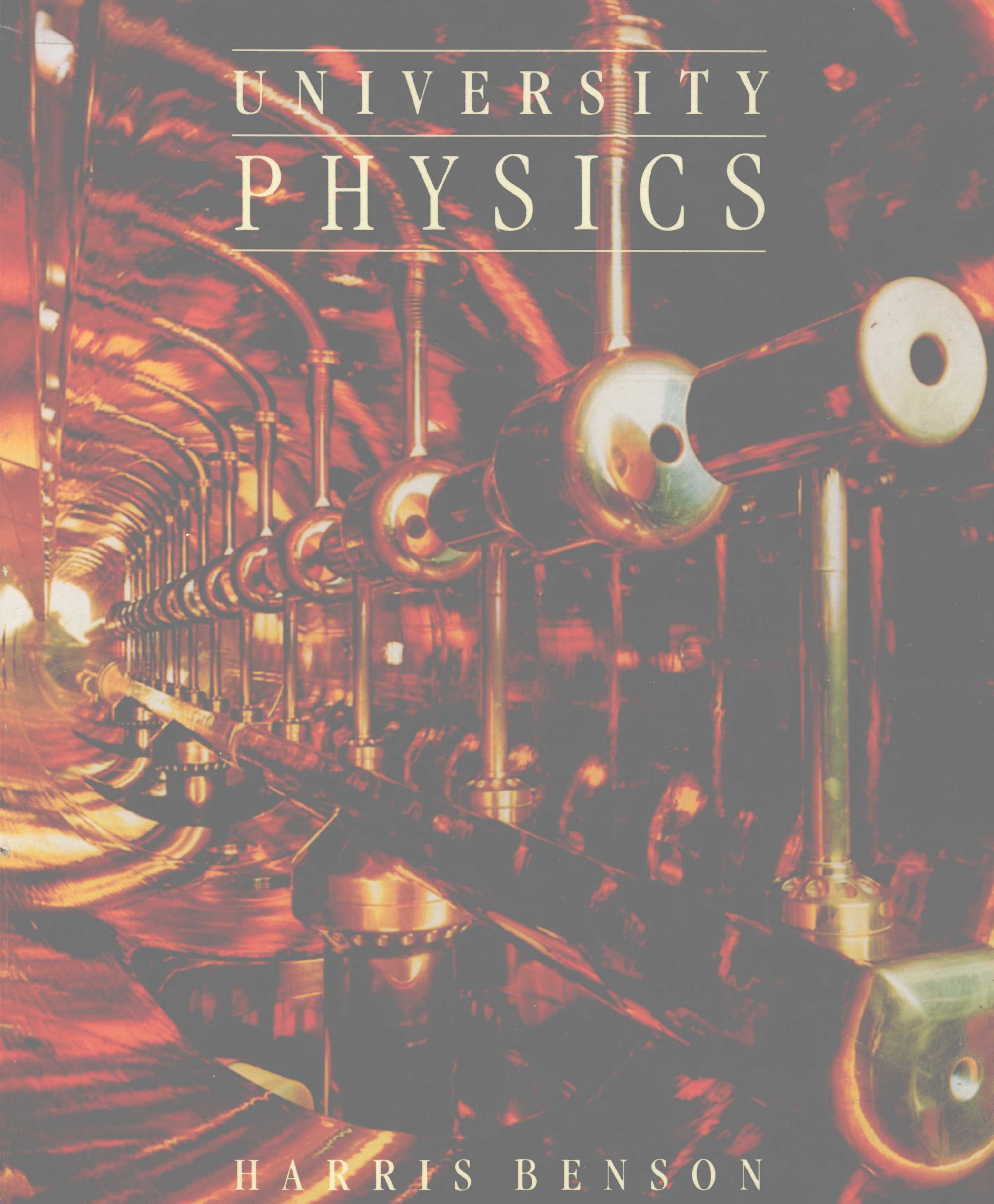
UNIVERSITY PHYSICS



HARRIS BENSON

UNIVERSITY PHYSICS

HARRIS BENSON
Vanier College

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To my family, Frances, Coleman and Emily, and to my mentors, D. L. Mills and A. A. Maradudin.

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Preface

This text is intended for a calculus-based introductory physics course for science and engineering students. It contains sufficient material for three semesters and, with appropriate omissions, it is easily adapted to a two-semester sequence. Students should be familiar with algebra and trigonometry (a review is included in Appendix B). Ideally, they should have completed one semester of calculus; however, calculus may also be taken concurrently with this course. Derivatives are used sparingly in the early chapters in mechanics, and integrals appear for the first time in Chapter 7 (Work and Energy). The book is based on the SI system of units; the British system is rarely mentioned.

Some of the features that are intended to enhance the appeal and effectiveness of the text are outlined below.

Accuracy

My primary objective has been to present concepts and principles clearly and correctly. I hope that the physics is free of even subtle misconceptions. In some optional sections I try to deal correctly with topics, such as the work–energy theorem for systems, that are inadequately treated in other texts. Attention is given to details such as the subtle question of signs in the application of Coulomb's law, in Faraday's law, or in Kirchhoff's loop rule for ac circuits. The concepts of emf and potential difference are clearly distinguished. The acceleration due to gravity and the gravitational field strength are given different symbols (although I do not dwell on this distinction).

Writing Style

I have tried to write in a simple, clear, and concise manner. This approach applies as much to the language as to the presentation of the mathematics and the notation used. The examples emphasize the important, or conceptually difficult, steps. Although the coverage is fairly complete, this textbook is significantly shorter than many that have appeared in recent years.

Pedagogy

I focus on central issues and highlight as few equations as possible (in the second color). Special cases, such as the "range formula" in projectile motion, are often discussed in an example and do not appear in the chapter summary. Also, I prefer not to present multiple versions of the same equation. For example, the intensity variation in the double-slit interference pattern appears only in terms of the phase difference (ϕ), and not in terms of the angular position (θ) or the vertical coordinate on the screen (y).

Questions, Exercises, and Problems

There is a large selection of questions, exercises, and problems. The questions are limited to those that students should find useful in improving their understanding. I avoid questions with no clear-cut answers. The exercises are keyed to the sections, whereas the problems are not. As an aid to students and instructors, both the exercises and the problems are graded according to two levels of difficulty: I and II. The answers to the odd-numbered exercises and problems are given in the text. A solutions manual containing brief solutions for all the exercises and problems is available only to instructors, not to students.

Content and Structure

The text includes almost all the traditional topics in classical physics. The last six chapters cover selected topics in modern physics. Basic material appears in a single-column format, whereas optional sections are in a two-column format. The overall structure is conventional. The discussions of the dot and cross products fit neatly into Chapter 2 but are easily postponed until they are needed. Chapters 15 to 17 on oscillations and waves may be combined with optics for a unified treatment of waves. The dynamics and energy aspects of satellite motion are discussed in Chapters 6 and 8, respectively. These topics may be delayed until Chapter 13 for a unified treatment of gravitation, but, as it stands, the whole of Chapter 13 may be omitted.

Pedagogical Aids

Major Points

These are placed at the beginning of each chapter and serve as a brief overview of the important concepts, laws, principles, and phenomena in that chapter.

In-Chapter Exercises

These are straightforward exercises that test a student's grasp of the preceding material. They encourage the active involvement of the student. Brief solutions, not just the answers, are provided at the end of each chapter.

Problem-solving Guides

Problem solving is arguably the most important aspect of a physics course. Throughout the text, but especially in the earlier chapters, there are problem-solving guides that outline a step-by-step approach for the analysis of problems.

The *chapter summaries* contain only the most important equations and a brief reiteration of the central principles and concepts. *Marginal notes* highlight important items throughout the text.

Worked Examples

A basic student complaint about physics texts is either that they do not have enough examples or that the examples do not adequately prepare them for the end-of-chapter problems. I address this issue by including a large number of nontrivial examples. Furthermore, their range of difficulty often encompasses the level of the tougher, multiple-step *problems,* rather than just that of the *exercises.* I occasionally address the frustrations likely to be encountered, such as false starts, extraneous roots, irrelevant data, difficulties in notation, and so on.

History

A distinctive feature of this text is the inclusion of historical material, which is included both as a pedagogical aid and as a source of enrichment. Historical material is used in the following ways:

1. To show how an idea, such as the conservation of energy, or a theory, such relativity or quantum mechanics, emerged and developed.
2. To portray physics more realistically as a human endeavor.

3. To present some items for their intrinsic interest (e.g., in occasional anecdotes).

Short historical accounts are blended into the text; they serve to illuminate the subject and to provide insight into the concepts. Longer case histories are placed in distinct *Historical Notes* (set in a two-column format with a different typeface). Some accounts deal with the development of topics such as the concept of inertia, Newton's law of gravitation, or electromagnetic induction. Others outline the elegant reasoning used, for example, by Huygens in his study of collisions, or by Einstein in his first derivation of $E = mc^2$. None of the historical material is tested in any way.

Students often have incorrect preconceived notions about the physical world. Consequently, a lucid presentation of some physical concept or theory may not, by itself, be sufficient to erase ideas that fit well into their worldviews. It is possible to directly address student misconceptions—for example, regarding inertia or heat—by outlining the historical development of the concept.

Introductory physics can easily seem to be a litany of conclusions—the end products of the labors of brilliant minds. Not only is this intimidating, but it also falsely portrays the subject as being established, rather than as a developing body of knowledge. Historical material can address this issue and also serve to reassure students that even great minds are confused before concepts get sorted out. Indeed, some of their own (incorrect) ideas were shared by great thinkers, such as Aristotle and Galileo.

The historical material has been kept fairly simple, and so proper credit has not been given to every scientist involved. Also, the discussions do not travel up all the original blind alleys. The history should be accurate, informative, and interesting, but it is not meant to be complete. This is a text with an historical flavor, not a book on the history of physics.

Special Topics

The *Special Topic* sections deal with interesting phenomena that relate directly to the material covered in the text. Some deal with the physics of everyday phenomena such as the tides, the rainbow, cat twists, atmospheric electricity, and the earth's magnetism. Others discuss up-to-date topics such as holography, superconductivity, magnetic levitation, scanning tunneling microscopy, and fusion power. Chapter 44, Elementary Particles, is written as a Special Topic; it has no examples or end-of-chapter material.

Color

Wherever it is appropriate, the clarity and effectiveness of the art has been improved by the use of multicolor diagrams. The presentation has been made more vivid and attractive by the inclusion of a large number of full-color photographs.

Reviewers

The comments and suggestions that I received from the reviewers listed below were invaluable in improving the manuscript. They showed great sensitivity to the needs of students and I am truly grateful to them for their help and advice.

Richard J. Anderson	University of Arkansas
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Edward J. Zimmerman	University of Nebraska.

Phil Eastman kindly agreed to check the wording of all the exercises and problems and to solve them independently. I am grateful for his prolonged efforts and useful comments. I thank Sid Freudenstein for his input to the solutions.

Consulting Editors

I was fortunate that two individuals agreed to act as consulting editors. Stephen G. Brush, a noted science historian, offered many suggestions regarding the historical material. I was able to address only some of the issues he raised. Kenneth W. Ford, an accomplished physicist and author himself, offered valuable advice on the pedagogy and the physics. I am grateful for his interest in this project and the encouragement he provided.

Acknowledgments

The development of such a project requires the contributions of many people. I am especially grateful to Heidi Udell and Logan Campbell who had enough confidence in me as an author to get this project started. Cathy Faduska strongly supported me while she was physics editor and subsequently guided the promotion of the book. I am greatly indebted to Cliff Mills for his unswerving confidence in my efforts. His kindness and sensitivity to an author's point of view made many tasks much easier than they might have been. I appreciate the input of John Haber, the developmental editor, who worked hard to improve the text. His many detailed comments were incisive and insightful.

I am thankful to Lorraine Burke and Ed Burke who did the page layout and coordinated many aspects of the production process. The black-and-white photographs were acquired by Mary Schoenthaler, while the photo research for the color photographs was expertly handled by John Schultz. Stella Kupferberg supervised the quality of the photographic reproduction. The art program was supervised by John Balbalis. I appreciate his suggestions for improving several figures. I also wish to acknowledge the help or contributions provided by Ann Renzi, Virginia Dunn, Cathy Donovan, Deborah Herbert, Joe Ford, Joan Kalkut, and Barbara Heaney.

I am grateful to my colleagues for their support. In particular, I must thank Luong Nguyen who encouraged my efforts from the beginning. He, along with David Stephen and Paul Antaki, provided me with much useful reference material. I appreciate several useful discussions with Michael Cowan and Jack Burnett.

Finally, I owe much to my wife, Frances, and to my children, Coleman and Emily. Without their patience, love, and tolerance over many years, this book could not have been completed. In future, my time with them will not be so measured.

I hope that students find this text makes their study of physics interesting and enjoyable. Any comments or corrections from students or faculty would be most welcome.

HARRIS BENSON
Vanier College,
821 Ste. Croix Blvd.,
Montreal, H4L 3X9

Contents

CHAPTER 1

Introduction

The study of bodies such as the Horsehead Nebula requires an understanding of the principles of physics.

Major Points

1. The meaning of the terms **model, principle,** and **theory.**
2. The **SI** system of **base units.** The conversion of units.
3. The use of **significant figures** to indicate the precision of data.
4. The use of **dimensional analysis** to check equations and to obtain relationships between physical quantities.
5. Reference frames. The **Cartesian** and **polar** coordinate systems.

1.1 WHAT IS PHYSICS?

Children have an insatiable curiosity about everything around them. Sights, sounds, and smells are a constant source of wonder and amazement. They are eager to learn about nature by looking at plants, birds, and insects, and by trying all sorts of experiments with straws, bottles, pebbles, water, paint, balls, and of course food and mud. They also love to take apart a watch or a mechanical toy to see what is inside and how it works. A scientist is a person who retains some of this childlike sense of curiosity and wonder about nature.

A scientist tries to make sense of how nature operates and to discover some underlying order in the vast array of natural phenomena. This can be done at various levels, each of which reveals a different layer of reality. Social science deals with the behavior of groups, psychology with individuals, biology with the structure and function of organisms, chemistry with the combinations of atoms.

Physics deals with the behavior and composition of **matter** and its **interactions** at the most fundamental level. It is concerned with the nature of *physical* reality, that is, only with things that can be measured by instruments. Its domain stretches from inside the tiny nucleus of an atom to the vast expanses of the universe. Geology, chemistry, engineering, and astronomy all require an understanding of the principles of physics. Physics also finds many applications in biology, physiology, and medicine.

Between 1600 and 1900, three broad areas were developed in what is called **classical physics:**

Classical physics

1. **Classical Mechanics:** The study of the motion of particles and fluids.
2. **Thermodynamics:** The study of temperature, heat transfer, and the properties of aggregations of many particles.
3. **Electromagnetism:** Electricity, magnetism, electromagnetic waves, and optics.

These three areas encompass virtually all the physical phenomena with which we are familiar. However, by 1905 it became apparent that classical ideas failed to explain several phenomena. Three important theories in **modern physics** are:

Modern physics

4. **Special Relativity:** A theory of the behavior of particles moving at high speeds. It led to a radical revision of our ideas of space, time, and energy.
5. **Quantum Mechanics:** A theory of the submicroscopic world of the atom. It also required a profound upheaval in our vision of how nature operates.
6. **General Relativity:** A theory that relates the force of gravity to the geometrical properties of space.

The goal of physicists is to explain physical phenomena in the simplest and most economical terms. For example, we want to discover the "ultimate" building blocks of matter. According to our present state of knowledge, ordinary matter is constructed from atoms, the atoms from nuclei and electrons, the nuclei from neutrons and protons, the neutrons and protons from quarks. Indeed all elementary particles (of which there are hundreds) can be constructed from just *two* basic types of particle: quarks and leptons.

As another example of the drive for economy, consider the apparently wide variety of forces we encounter in nature: forces exerted by ropes, springs, fluids, electric charges, magnets, the earth and the sun, chemical forces, nuclear forces, and so on. Despite this great variety, physicists can explain all physical phenomena in terms of just four basic interactions. Their ranges and relative strengths are summarized in Table 1.1.

TABLE 1.1 THE BASIC INTERACTIONS

Interaction	Relative Strength	Range
Strong	1	10^{-15} m
Electromagnetic	10^{-2}	Infinite
Weak	10^{-6}	10^{-17} m
Gravitational	10^{-38}	Infinite

The basic interactions

The **gravitational** interaction produces an attractive force between all particles. It is responsible for our weight, causes apples to fall, and holds the planets in their orbits around the sun. The **electromagnetic** interaction between electric charges is manifested in chemical reactions, light, radio and TV signals, X rays, friction, and all the other forces we experience every day. It also governs the transmission of signals along nerve fibers. The **strong** interaction between quarks and most other subnuclear particles holds particles within the nucleus. The **weak** interaction between quarks and leptons is associated with radioactivity. In 1983 it was confirmed that the electromagnetic and weak interactions are different manifestations of a more basic **electroweak** interaction. Progress has also been made in attempts to combine the strong and electroweak interactions in a single **grand unified theory.** Clearly, the dream of physicists is to discover a *single* fundamental interaction from which all forces can be derived.

1.2 CONCEPTS, MODELS, AND THEORIES

In physics we deal with concepts, laws, principles, models, and theories. Let us briefly consider the meaning of each of these terms.