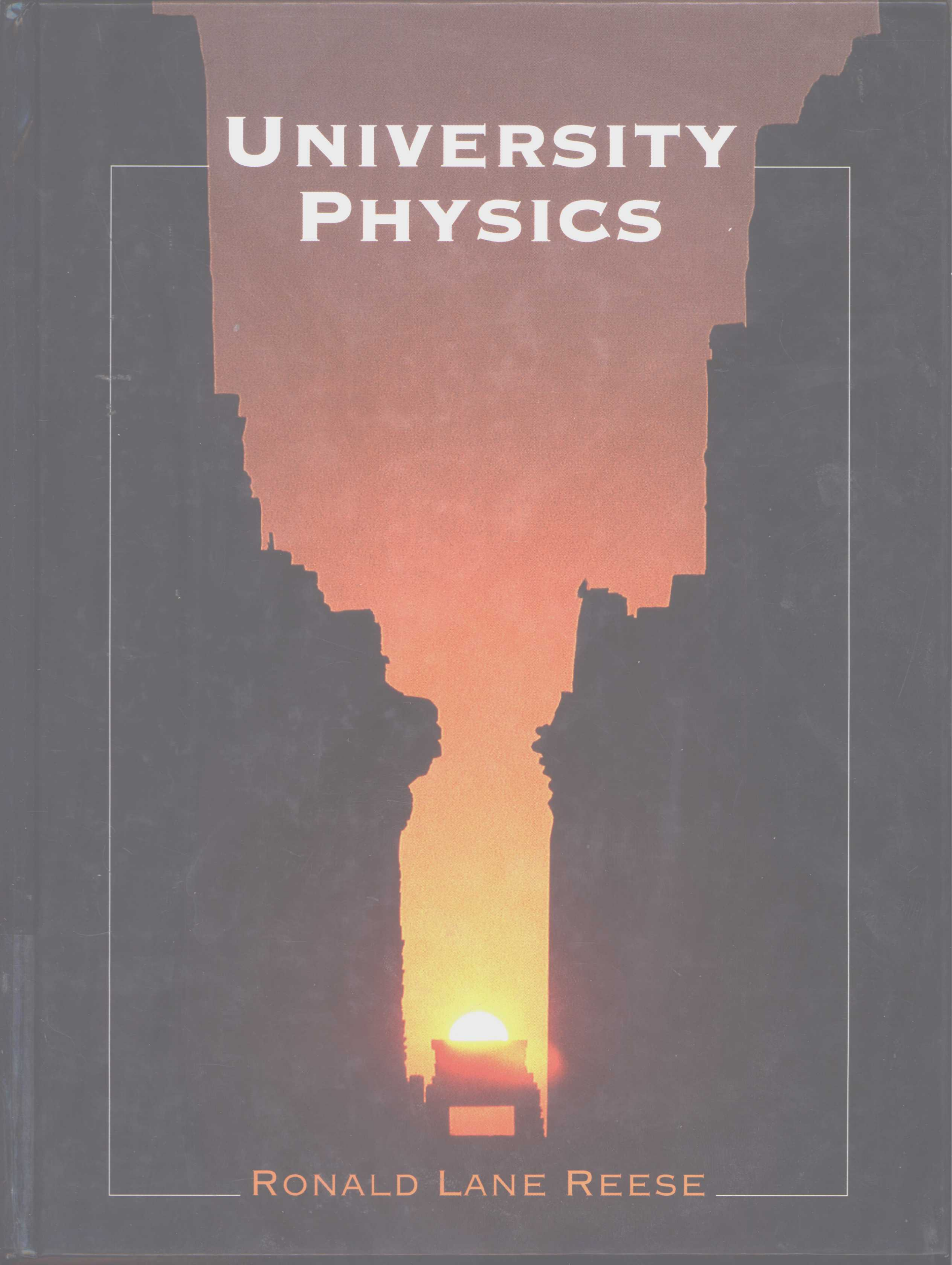
UNIVERSITY PHYSICS



RONALD LANE REESE

UNIVERSITY PHYSICS

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Credits continue on page C.1, at the back of the book.

UNIVERSITY PHYSICS

Magna opera Domini:
exquisita in omnes voluntates ejus

[*Psalmi* CXI, v 2]*

The past:
In loving memory of my mother
Edith Lemberg Reese
(1906–1984)

and mother-in-law
Bertha Marie Carlson
(1907–1981)

and in honor of my father
Harold Augustus Reese Sr.
(1906–)

The present:
With grateful thanks for the love
and devotion of my wife
Edith Joanne Carlson Reese

The future:
For the priceless blessings
of a wonderful son and daughter
Daniel Austin Reese
Anna-Loren Reese

* The Hexaplar Psalter, Samuel Bagster and Sons, London, 1843.

PREFACE

GOALS

In recent years much active discussion and debate has revolved around just what body of knowledge and skills science and engineering students should take from a university physics course. An obvious related issue is how best to achieve the desired learning goals. As the primary instructional resource for the student outside the classroom and the professor's office, the textbook naturally has been a focus of these discussions. Over the last 30 years or so a "standard model" of university physics textbook has evolved to the point of extensive refinement. Several generations of future scientists and engineers have been introduced to the powerful ideas of physics through these texts, and certainly we should acknowledge the many strengths of these books while considering *how we can improve on them as learning tools for today's physics students.*

When writing this text, I decided from the onset that the text should follow the twin educational commandments of Alfred North Whitehead: "Do not teach too many subjects, and what you teach, teach thoroughly." I believe that Whitehead's statement, at a basic level, reflects two of the most common themes emerging from what has come to be known as the physics reform movement. Thus, while this text was not written as a reform textbook, it nonetheless embraces the spirit of many reform goals, such as better integration of modern physics topics, a stronger emphasis on conceptual understanding, and an attention to different learning styles. Most importantly, however, this book is written for students, to allow them not only to learn the tools that physics provides but also to see why they work and the beauty of the ideas that underlie them.

TEXT OVERVIEW

A Focused Perspective

One of the great triumphs of physics is the amount of understanding that comes from a relatively small investment of fundamental ideas and principles. Students, however, often see the course as a random assortment of 25 to 30 topics deemed worthy of chapter status. Unifying concepts, such as conservation laws and field theory, can be lost amidst the mountainous amount of material. Students frequently fail to see just how little must be known to describe as much of nature as possible. Thus, a central goal of this text is to help students develop a thorough *understanding* of the *principles* of the basic areas of physics: kinematics, dynamics, waves, thermodynamics, electromagnetism, optics, relativity, and modern physics. It is better to build technical knowledge upon a firm foundation of fundamental principles than on a large collection of mere formulas.

Since most of us do not innately discern simplifying patterns and connections when faced with the seemingly complex, we become good and experienced students of physics through steady practice. This is a fundamental pedagogical issue, and one that this text addresses clearly through focusing on many of the difficulties encountered by students when studying physics, problems mentioned by Arnold Arons in *A Guide to Introductory Physics Teaching*, and by others in the educational literature of physics. Thus, the book

- continually integrates the most significant material from previous chapters into new material, in keeping with Arons's admonition to "spiral back" frequently, for greater insight and retention.
- provides an accurate conceptual understanding of fundamental physical principles by placing great emphasis on these principles and how they arose.
- recognizes and points out the limits of applicability of the theories and equations of physics. It can be just as important, after all, to know what doesn't apply as what does.
- stresses connections between topics by incorporating many aspects of contemporary physics into a mix of traditional topics. This goal is carried through in all aspects of the text—exposition, examples, questions, problems, and investigative projects.

A Thorough Development

Some recent texts have jockeyed to outdo each other by reducing the number of overall pages. While brevity is often a laudatory goal, it can sometimes also work to defeat other, more important purposes. For true conceptual understanding to take place, a "fewer pages is more" approach can make the physics learning experience similar to trying to extrapolate the beauty and subtleties of a Shakespearean drama by reading a summary of the plot line. This text, while no longer than many other university physics texts, has been written with the primary philosophy that students need a text that lays a careful, detailed groundwork for strong conceptual understanding and the development of mature problem-solving skills. For example, much research has recently been done on the different learning styles that students apply when first studying new material, but for a text to try to implement pedagogical structure to these different learning styles and goals (such as multiple problem-solving approaches or collaborative learning techniques), it is inevitable that the lesser goal of brevity must be sacrificed. In a similar vein, students often complain that the examples in the text do not prepare them well for the more challenging homework problems, where more than one idea may be addressed. Page length can be kept down by focusing on just the most straightforward examples, but students also need to see how the principles can be applied to more involved scenarios. I have placed special emphasis on thoroughly preparing students for the homework sets through strong emphasis (and reemphasis) on problem-solving techniques, by frequent references to and explanations of common misunderstandings, and by providing a set of examples that address both single-concept problem solving and the application of fundamental principles to longer, multiconcept problems. The ability to question whether results are reasonable has been fostered throughout these examples.

The text contains an ample selection of sections from which individual instructors can design a course compatible with their academic institution and student audience. Numerous sections, typically at the end of chapters, are listed as optional (designated by a *) and may be omitted by instructors preferring a leaner course. Others may want to choose their own path, including some of the optional sections while omitting others.

Features

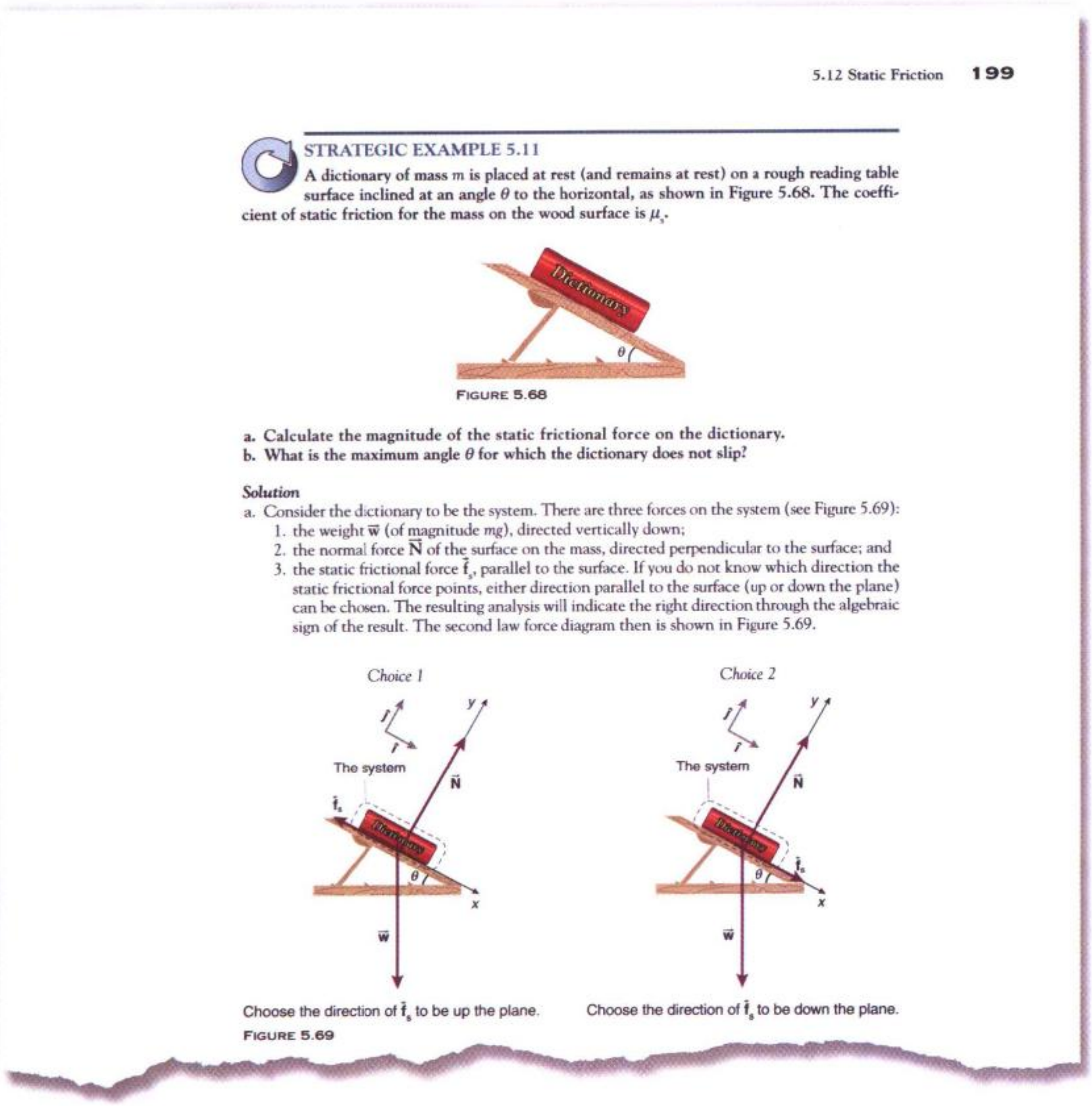
STYLE

Physics is a great story, and in this text I have attempted to tell that story in as lively, clear, and precise a manner as possible. Students sometimes fail to see how the topics connect to each other or to the world outside the classroom. Thus, I have placed great emphasis on introducing each new topic by describing how it relates to experiences and phenomena with which the student is already familiar or to topics previously discussed. There is also no reason that reading a physics text shouldn't be fun (or at least not a chore). My philosophy is that occasional lapses into whimsy are a small price to pay if the result is that students stay more engaged with the reading. Finally, by filling in the details that are sometimes left unstated, this text should help students better bridge the gaps where misconceptions can arise.

STRATEGIC EXAMPLES AND OTHER EXAMPLES

A strong emphasis has been placed on beginning almost all Examples with a few, fundamental principles and equations, rather than specialized equations of secondary importance. Strategic Examples address the application of fundamental principles to longer problems; they are discussed in great detail, which students find particularly helpful in developing their own problem-solving abilities. Moreover, many of the end-of-chapter problems mirror the methodological details of the Strategic Examples.

A unique feature of this text is that many of the Examples are solved in more than one way. All too often students suffer from the perception that they must be doing a problem incorrectly because a fellow student or even the professor has set it up differently. By working selected problems using different choices of signs, coordinate axes, or even overall approach, these Examples



5.12 Static Friction 199

STRATEGIC EXAMPLE 5.11

A dictionary of mass m is placed at rest (and remains at rest) on a rough reading table surface inclined at an angle θ to the horizontal, as shown in Figure 5.68. The coefficient of static friction for the mass on the wood surface is μ_s.

FIGURE 5.68

a. Calculate the magnitude of the static frictional force on the dictionary.
b. What is the maximum angle θ for which the dictionary does not slip?

Solution

a. Consider the dictionary to be the system. There are three forces on the system (see Figure 5.69):
1. the weight $\vec{w}$ (of magnitude mg), directed vertically down;
2. the normal force $\vec{N}$ of the surface on the mass, directed perpendicular to the surface; and
3. the static frictional force $\vec{f}_s$, parallel to the surface. If you do not know which direction the static frictional force points, either direction parallel to the surface (up or down the plane) can be chosen. The resulting analysis will indicate the right direction through the algebraic sign of the result. The second law force diagram then is shown in Figure 5.69.

Choose the direction of $\vec{f}_s$ to be up the plane. Choose the direction of $\vec{f}_s$ to be down the plane.

FIGURE 5.69

also help students develop intuition on how certain choices can simplify later calculations compared with other alternatives.

Conceptual Notes

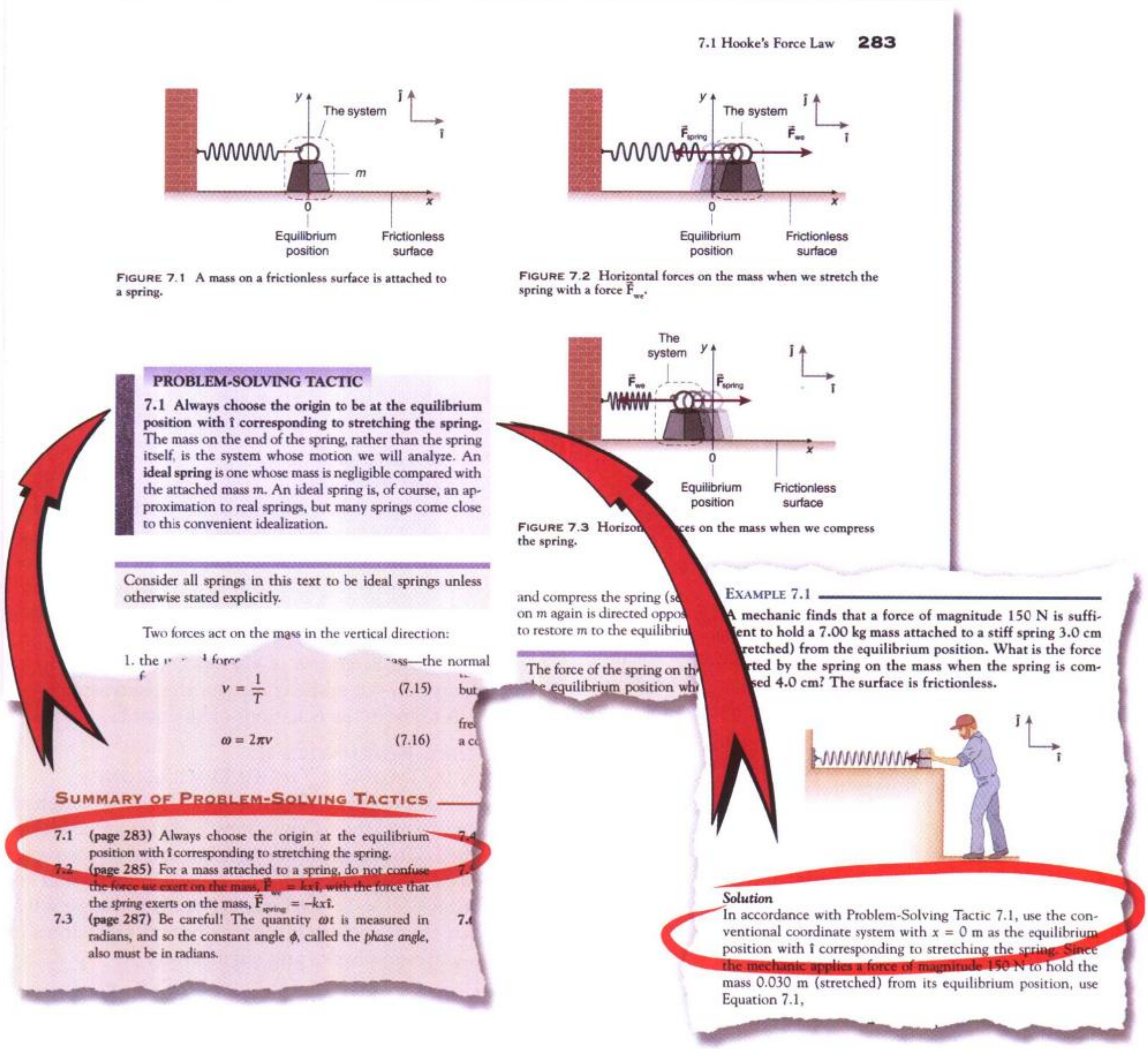
Throughout the text, key points of each section have been highlighted with shading. Importantly, these Conceptual Notes are not just the most important equations—they focus on the principal ideas and concepts (and sometimes equations) that a student should take from each section. My students have found the Conceptual Notes very useful as a reviewing tool for tests and quizzes.

Problem-Solving Tactics

In addition to useful problem-solving hints, the Problem-Solving Tactics also provide warnings to students about common errors and how to avoid them. Often these important tips of the trade are also integrated into the text discussion. For example, specific Problem-Solving Tactics are often cross-referenced in some of the Examples. At the end of each chapter a summary of that chapter's Problem-Solving Tactics is included, with a page reference to the related text discussion for each tactic.

Questions

A common student lament is that "I understand the material; I just can't do the problems." The questions within and at the end of each chapter test a student's understanding of concepts before the student is asked to apply these concepts to more complex or quantitative situations in the problems. Some of these questions entail a short qualitative explanation, whereas others may require a short back-of-the-envelope calculation or even a quick and dirty experiment to determine the approximate magnitude of a quantity.



Problems

The development of successful problem-solving techniques is an essential goal for all introductory physics students. To help students hone these abilities, many of the problems involve a multistep approach in which students are guided through the problem with specific questions that enable them first to find all the pieces and then to put them together. Additionally, many of the problems mimic the approach of the Strategic Examples so that there is a strong correlation between the presentation of the material and the problems that a student is expected to be able to solve.

Since the real world is awash with information, the problems occasionally include irrelevant or superfluous information. This teaches a student to discriminate between what is needed and what is not. It also may be necessary to consult an appropriate table in the chapter or on the front and back inside covers to find numerical values of standard constants or parameters. In both the examples and problems, attention is paid to the consistent use of significant figures.

Three levels of difficulty are provided, with unbulleted, bulleted (•), and double-bulleted (‡) problems representing straightforward, moderate, and more difficult problems, respectively. Those problems with red numbers include answers at the back of the book and are solved in the Student's Solutions Manual. I have personally solved all of the problems, and the problem sets have been additionally fine-tuned by actual classroom usage over the course of several years.

Investigative Projects

These projects are highly amenable to collaborative group work and are of the following types:

- *Expanded Horizons*—These projects are well suited to journal club research, discussion, and supplementary reading.
- *Lab and Field Work*—Doing physics is an important part of studying physics. In these projects, students are asked to design and carry out experiments either with other students or the professor.
- *Communicating Physics*—A key developmental goal for any student is the ability to write about and discuss technical topics. Practice on these written and oral communication skills is provided by these project topics, which are ideal for writing-intensive assignments, public speaking, and community service opportunities.

The projects are interesting to read, even if never performed or assigned, since they indicate the breadth and depth of applications of chapter material. As such, they can help stimulate inquiry, class discussion, and faculty–student interaction. Most of the projects are provided with references that serve as a guide (and entryway) to the appropriate literature.

Summaries

Each chapter concludes with an extensive summary that, when combined with the Conceptual Notes and the Summary of Problem-Solving Tactics, provides an ideal in-text study guide for the student.

Quotations

I have used these frequently throughout the text to cast the subject matter in a different light, be it serious or whimsical. Great writing (communication!) from the past is central to a real understanding of any discipline, even physics.

Mathematical Level

This text assumes a familiarity with calculus comparable to what a student would obtain from a high school calculus course (with or without advanced placement credit). Of course, additional calculus is useful when taken concurrently with this course. No prior knowledge of physics is presumed.

Precision

Effective, unambiguous communication in physics requires clear and consistent use of the technical vocabulary and a solid understanding of the meaning of the technical notation. This tenet has informed the presentation throughout the book.

Chapter Contents

Chapter 1 Preludes

An overview of physics is presented along with an introduction to measurement standards of the SI unit system, distinguishing them from common units of convenience. The various meanings of the equal sign are discussed as well as estimation and order of magnitude calculations. The distinction is made between precision and accuracy. The notion of significant figures is discussed in the context of common mathematical operations such as multiplication (and division) and addition (and subtraction). Having made these points, the text does not ignore their use and makes consistent use of significant figures throughout its examples and problems so that students realize their importance even outside a laboratory context.

Chapter 2 A Mathematical Toolbox: An Introduction to Vector Analysis

The proper and consistent use of vectors is very important to success in physics. This chapter and the rest of the book distinguish clearly among a vector, its magnitude, and its components with respect to a chosen coordinate system. Vector addition and subtraction are designated by boldface **+** and **−** to distinguish the operations clearly from their scalar counterparts, a source of much student confusion in problem solving.

Chapter 3 Kinematics I: Rectilinear Motion

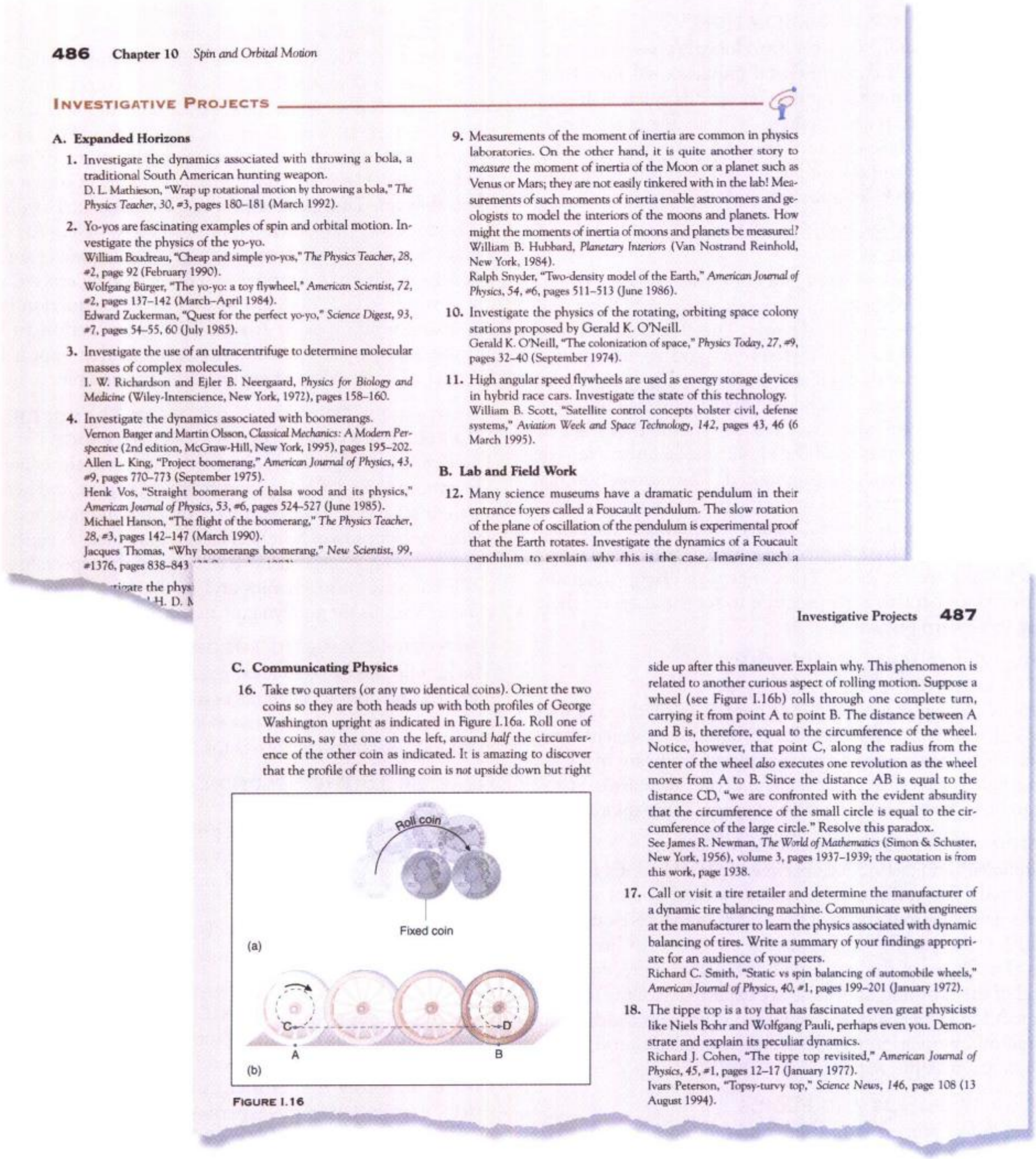
The notion of a particle is addressed. A one-dimensional vector approach is used so its extension to two- and three-dimensional motion in Chapter 4 is seamless and painless. The choices that a student must make in establishing a coordinate system for a problem and the consequences of that choice in tailoring the (few) fundamental kinematic equations to a problem are stressed throughout. Consistent use of vectors and vector terminology takes the mystery out of the choice for the signs associated with the various terms in the equations of kinematics.

Chapter 4 Kinematics II: Motion in Two and Three Dimensions

The vector approach of Chapter 2 easily allows extension to motion in two and three dimensions. Relative velocity addition is examined. Uniform and nonuniform circular motion are approached by introducing both the angular velocity and angular acceleration vectors so students are ready for more advanced work with these vectors in upper-division mechanics or dynamics courses in physics and engineering.

Chapter 5 Newton's Laws of Motion

An overview of fundamental particles and forces is presented. The concept of force and its measurement are introduced stressing how important it is to define clearly the system under



486 Chapter 10 *Spin and Orbital Motion*

INVESTIGATIVE PROJECTS

A. Expanded Horizons

1. Investigate the dynamics associated with throwing a bola, a traditional South American hunting weapon.
D. L. Mathieson, "Wrap up rotational motion by throwing a bola," *The Physics Teacher*, 30, #3, pages 180–181 (March 1992).

2. Yo-yos are fascinating examples of spin and orbital motion. Investigate the physics of the yo-yo.
William Boudreau, "Cheap and simple yo-yos," *The Physics Teacher*, 28, #2, page 92 (February 1990).
Wolfgang Bürger, "The yo-yo: a toy flywheel," *American Scientist*, 72, #2, pages 137–142 (March–April 1984).
Edward Zuckerman, "Quest for the perfect yo-yo," *Science Digest*, 93, #7, pages 54–55, 60 (July 1985).

3. Investigate the use of an ultracentrifuge to determine molecular masses of complex molecules.
I. W. Richardson and Ejler B. Neergaard, *Physics for Biology and Medicine* (Wiley-Interscience, New York, 1972), pages 158–160.

4. Investigate the dynamics associated with boomerangs.
Vernon Barger and Martin Olsson, *Classical Mechanics: A Modern Perspective* (2nd edition, McGraw-Hill, New York, 1995), pages 195–202.
Allen L. King, "Project boomerang," *American Journal of Physics*, 43, #9, pages 770–773 (September 1975).
Henk Vos, "Straight boomerang of balsa wood and its physics," *American Journal of Physics*, 53, #6, pages 524–527 (June 1985).
Michael Hanson, "The flight of the boomerang," *The Physics Teacher*, 28, #3, pages 142–147 (March 1990).
Jacques Thomas, "Why boomerangs boomerang," *New Scientist*, 99, #1376, pages 838–843

...tigate the phys...
...H. D. M...

9. Measurements of the moment of inertia are common in physics laboratories. On the other hand, it is quite another story to *measure* the moment of inertia of the Moon or a planet such as Venus or Mars; they are not easily tinkered with in the lab! Measurements of such moments of inertia enable astronomers and geologists to model the interiors of the moons and planets. How might the moments of inertia of moons and planets be measured?
William B. Hubbard, *Planetary Interiors* (Van Nostrand Reinhold, New York, 1984).
Ralph Snyder, "Two-density model of the Earth," *American Journal of Physics*, 54, #6, pages 511–513 (June 1986).

10. Investigate the physics of the rotating, orbiting space colony stations proposed by Gerald K. O'Neill.
Gerald K. O'Neill, "The colonization of space," *Physics Today*, 27, #9, pages 32–40 (September 1974).

11. High angular speed flywheels are used as energy storage devices in hybrid race cars. Investigate the state of this technology.
William B. Scott, "Satellite control concepts bolster civil, defense systems," *Aviation Week and Space Technology*, 142, pages 43, 46 (6 March 1995).

B. Lab and Field Work

12. Many science museums have a dramatic pendulum in their entrance foyers called a Foucault pendulum. The slow rotation of the plane of oscillation of the pendulum is experimental proof that the Earth rotates. Investigate the dynamics of a Foucault pendulum to explain why this is the case. Imagine such a

Investigative Projects 487

C. Communicating Physics

16. Take two quarters (or any two identical coins). Orient the two coins so they are both heads up with both profiles of George Washington upright as indicated in Figure I.16a. Roll one of the coins, say the one on the left, around *half* the circumference of the other coin as indicated. It is amazing to discover that the profile of the rolling coin is *not* upside down but right side up after this maneuver. Explain why. This phenomenon is related to another curious aspect of rolling motion. Suppose a wheel (see Figure I.16b) rolls through one complete turn, carrying it from point A to point B. The distance between A and B is, therefore, equal to the circumference of the wheel. Notice, however, that point C, along the radius from the center of the wheel *also* executes one revolution as the wheel moves from A to B. Since the distance AB is equal to the distance CD, "we are confronted with the evident absurdity that the circumference of the small circle is equal to the circumference of the large circle." Resolve this paradox.
See James R. Newman, *The World of Mathematics* (Simon & Schuster, New York, 1956), volume 3, pages 1937–1939; the quotation is from this work, page 1938.

FIGURE I.16

17. Call or visit a tire retailer and determine the manufacturer of a dynamic tire balancing machine. Communicate with engineers at the manufacturer to learn the physics associated with dynamic balancing of tires. Write a summary of your findings appropriate for an audience of your peers.
Richard C. Smith, "Static vs spin balancing of automobile wheels," *American Journal of Physics*, 40, #1, pages 199–201 (January 1972).

18. The tippe top is a toy that has fascinated even great physicists like Niels Bohr and Wolfgang Pauli, perhaps even you. Demonstrate and explain its peculiar dynamics.
Richard J. Cohen, "The tippe top revisited," *American Journal of Physics*, 45, #1, pages 12–17 (January 1977).
Ivars Peterson, "Topsy-turvy top," *Science News*, 146, page 108 (13 August 1994).

consideration. The significance and importance of all three of Newton's laws of motion are addressed. Both second law and third law force diagrams are discussed. The intricacies of special forces such as weight, tension, and static and kinetic friction are explored. Inertial and noninertial reference frames are contrasted.

CHAPTER 6 THE GRAVITATIONAL FORCE AND THE GRAVITATIONAL FIELD

Newton's law of universal gravitation is *not* presented as a *fait accompli* as if inscribed in stone; rather the process by which Newton deduced the law is explored. The gravitational shell theorems are discussed and applied (and proved in an appendix). Kepler's laws of planetary motion are discussed, along with a convenient simplification to the third law commonly used in astronomy (using customized units: years and astronomical units). Newton's form for Kepler's third law is derived. The concept of the gravitational field is introduced so that parallels with it may be exploited later when studying electricity and magnetism. Gauss's law for the gravitational field is proved, so that further parallels with electromagnetism can be made. Many of the problems consider contemporary astronomical applications.

CHAPTER 7 HOOKE'S FORCE LAW AND SIMPLE HARMONIC OSCILLATION

Hooke's law for springlike forces is introduced. A horizontal and a vertical spring (with the additional gravitational force) are compared. Simple harmonic oscillation and its relationship to uniform circular motion are discussed. The simple pendulum is introduced as well as the oscillatory gravitational motion through a uniform sphere. Damped simple harmonic oscillation and forced oscillation with resonance are explored.

CHAPTER 8 WORK, ENERGY, AND THE CWE THEOREM

Students typically think of work and energy as the same thing. The similarities and distinctions between work and energy are explored as well as the concept of power. The classical work–energy theorem (called the CWE theorem) and its limitations caused by the neglect of thermal effects are thoroughly examined to set the stage for a more general and encompassing conservation of energy theorem when we consider thermodynamics in Chapter 13. The importance of the choice made for the zero of a potential energy function is emphasized. The connection between the local form for the gravitational potential energy (mgy, with $\hat{\jmath}$ up) and the more general form ($-GMm/r^2$) is discussed. Applications to astrophysical problems such as the escape speed and black holes are explored. The concept of energy diagrams also is introduced at this early juncture to set the stage for their later use in modern physics.

CHAPTER 9 IMPULSE, MOMENTUM, AND COLLISIONS

The general principles are stressed rather than a plethora of specialized equations for collisions. The contemporary idea of force transmission by particle exchange is explored by means of a classical example for repulsive forces. The center of mass is introduced and the dynamics of a system of particles is explored.

CHAPTER 10 SPIN AND ORBITAL MOTION

The similarities and distinctions between spin and orbital motion are explored. The rotational dynamics of rigid bodies with at least one symmetry axis through the center of mass is examined, emphasizing the parallels to analogous equations in linear dynamics. The shape of the spinning Earth and the precession of tops and of the spinning Earth also are explored. Rolling motion and a model of a wheel also are examined to explain the difficult but common observation that less force is needed to roll rather than to drag a massive system.

CHAPTER 11 SOLIDS AND FLUIDS

The mechanical properties of solids and fluids are investigated. The variation of pressure with depth or height in a liquid is examined, leading to an equation giving students great freedom to approach a problem with many different coordinate choices. Archimedes' principle and the stability of floating systems are explored (why things such as submarines, ships, or poles will float in one orientation but are unstable in another orientation). Bernoulli's principle is derived from the CWE theorem. Capillary action, nonideal fluids, and viscous flow also are discussed.

CHAPTER 12 WAVES

General waves and their wavefunction, waveform, and oscillatory behavior are discussed. Nonsinusoidal periodic waves are discussed before sinusoidal periodic waves so the distinction between the oscillatory behavior of the wave at a fixed place can be clearly distinguished from its waveform at a fixed time. The classical wave equation is derived so that it can be contrasted with the Schrödinger equation in Chapter 27. Waves on strings are introduced. A unique section explores the nature of a sound wave and the relationship between the particle position and the pressure or density wave. The measurement of sound intensity and sound level is discussed so that students become aware of common sound levels that can damage their hearing. The acoustic Doppler effect treats motion of the source and/or observer as well as the effect of a wind. Superpositions of waves to form standing waves are applied to strings and both open and closed pipes. The superposition leading to wave beats is explored as well as the distinction between phase and group speeds. A simplified introduction to Fourier analysis leads to wave uncertainty relations that appear later in Chapter 27 as the Heisenberg uncertainty principle.

CHAPTER 13 TEMPERATURE, HEAT TRANSFER, AND THE FIRST LAW OF THERMODYNAMICS

The definition of a simple thermodynamic system is presented. The intuitive yet difficult concepts of temperature and heat transfer are introduced. Thermal effects in solids, liquids, and gases as well as mechanisms of heat transfer are examined. A general statement of energy conservation is developed that specializes to the CWE theorem of mechanics and to the first law of thermodynamics. Various thermodynamic processes for gases are explored.

CHAPTER 14 KINETIC THEORY

The kinetic theory of an ideal gas is presented as well as its limitations. The notion of degrees of freedom and the effect of quantum mechanics on the effective number of degrees of freedom are discussed. Adiabatic processes for ideal gases also are presented.

CHAPTER 15 THE SECOND LAW OF THERMODYNAMICS

The need for this great unifying principle is discussed in the context of why some things happen and others do not. Thermodynamic models for engines and refrigerators are presented and related to the second law. The nonintuitive concept of entropy is carefully developed as well as a classical model that explores the Boltzmann statistical interpretation of the meaning of entropy.

CHAPTER 16 ELECTRIC CHARGES, ELECTRIC FORCES, AND THE ELECTRIC FIELD

The chapter begins with an exploration of how electrical effects were distinguished from magnetic effects. The question of just what is meant by the term electric charge is confronted by a careful exploration of the experiments that led to the discovery of the two types of charge property and why Franklin's subsequent naming of them (as positive and negative charges) was particularly useful and convenient. Charge quantification is distinguished from charge quantization. The concept of the electric field is developed by exploring the similarities and differences between electricity and gravitation. Gauss's law for the electric field is developed from the parallel law for the gravitational field.

CHAPTER 17 ELECTRIC POTENTIAL ENERGY AND THE ELECTRIC POTENTIAL

The often confused and subtle distinction between these two concepts is thoroughly explored. The electron-volt energy unit is introduced and its convenience illustrated. Lightning rods also are discussed.

Chapter 18 Circuit Elements, Independent Voltage Sources, and Capacitors

Chapter 19 Electric Current, Resistance, and dc Circuit Analysis

The terminology and methodology used for circuit analysis conforms to the standard conventions used in electrical engineering so the transition between physics and electronics can be made easily. The text clearly explains why positive charge flowing one way is equivalent to negative charge flowing in the opposite direction, a point of much mystification to students.

Chapter 20 Magnetic Forces and the Magnetic Field

The need for a magnetic field is introduced by contrasting it with the electric field and its effects on electric charge. North and south magnetic poles are defined clearly rather than assumed to be obvious or innate. Applications include a velocity selector, mass spectrometer, and the Hall effect for determining the sign of the charge carriers of a current. Magnetic forces on currents lead to the torque on a current loop and the electric motor. The source of a magnetic field is introduced by exploring the parallels with both gravitational and electric fields. Gauss's law for the magnetic field, Ampere's law, the concept of a displacement current, and the Ampere–Maxwell law are discussed. The magnetic field of the Earth and how its reversals were discovered (via sea-floor sediments) also are explored to connect with another exciting discipline of the sciences that students see as remote from physics. *Nothing* is remote from physics!

Chapter 21 Faraday's Law of Electromagnetic Induction

The technological importance of Faraday's law is presented, leading to the development of an ac generator. The Maxwell equations are celebrated. The Maxwell equations in a vacuum are examined, leading to self-sustaining electromagnetic waves and the identification of such waves with light. Inductors and ideal transformers as standard circuit elements are explored using the standard engineering conventions.

Chapter 22 Sinusoidal ac Circuit Analysis

The typical approach to ac circuits in physics makes them seem impossibly complicated to students. In contrast, a brief introduction to complex variables permits the treatment of sinusoidal ac circuits via an extension of dc circuit analysis techniques, as is standard practice in electrical engineering. The use of current, potential difference, and voltage source phasors and the concept of impedance mean that sinusoidal ac circuit analysis then is reduced to the algebra of complex numbers.

Chapter 23 Geometric Optics

The simple Cartesian sign convention is used for mirrors, single surface refraction, and lenses, rather than a host of different, complex, and difficult to memorize mirror and lens conventions. Applications include the vertebrate eye, cameras, microscopes, and telescopes.

Chapter 24 Physical Optics

Interference via wavefront division (single, double, and multiple slit experiments as well as diffraction gratings) and amplitude division (thin-film interference) all are explored. Polarization and optical activity are discussed.

Chapter 25 The Special Theory of Relativity

Classical Galilean relativity is reviewed as well as the need for change. With the two postulates of special relativity, time dilation and length contraction are explored and used to derive the Lorentz transformation equations. The apparent relativistic paradox that *each* reference frame measures clocks in the *other* reference frame to run slow and lengths parallel to the motion to be shorter is confronted directly and resolved with a specific example. The existence of superluminal jets in astrophysics is found to be an optical illusion. The relativistic Doppler effect is explored, leading to the startling realization that for a source approaching with a nonzero impact parameter, the transition from a blue to a red shift occurs *before* the source is transverse to the line of sight. Questions of energy, momentum, the CWE theorem, and the relationship among mass, energy, and particles all are explored. The reason that the speed of light is an unreachable speed limit for material particles is discussed. The so-called mass–energy equivalence is clearly and properly addressed. Space–time diagrams are introduced and used to show why travel into the past (an idea with much student interest in view of contemporary culture) is forbidden in special relativity. The electromagnetic implications of relativity also are examined. The general theory of relativity and its classical tests are discussed using a qualitative approach.

Chapter 26 An Aperitif: Modern Physics

The fortuitous discoveries of the electron, x-rays, and radioactivity are explored. The nuclear model of the atom is developed from the viewpoint that it was quite a radical proposal by Rutherford, rather than being simply obvious. The photoelectric effect and Compton scattering are used to justify the existence of the photon. The Bohr model and its limitations are explored. The biological effects of radiation and dosage units are discussed. The de Broglie hypothesis is introduced and questions raised about the meaning of a particle-wave.

Chapter 27 An Introduction to Quantum Mechanics

The Heisenberg uncertainty principle is explored as well as the famous double slit experiment. The meaning of the wavefunction is assessed. Heuristic arguments lead to the Schrödinger equation.

A Complete Ancillary Package

The following comprehensive teaching and learning package accompanies this book.

For the Student

Media Resources

Brooks/Cole Physics Resource Center is Brooks/Cole's website for physics, which contains a homepage for *University Physics*. All information is arranged according to the text's table of contents. Students can access flash cards for all glossary terms, supplementary practice and conceptual problems, practice quizzes for every chapter, and hyperlinks that relate to each chapter's contents.

InfoTrac® College Edition is an online library available FREE with each copy of each volume of *University Physics*. (Due to license restrictions, *InfoTrac College Edition* is only available to college students in North America upon the purchase of a new book.) It gives students access to full-length articles—not simply abstracts—from more than 700 scholarly and popular periodicals, updated daily and dating back as much as four years. Student subscribers receive a personalized account ID that gives them four months of unlimited Internet access—at any hour of the day—to readings from *Discover*, *Science World*, and *American Health* magazines.

OTHER STUDY AIDS

Student Solutions Manual in two volumes by Ronald Lane Reese, Mark D. Semon, and Robin B. S. Brooks includes answers and solutions to every other odd numbered end-of-chapter problem.

FOR THE INSTRUCTOR

Complete Solutions Manual in two volumes, by Ronald Lane Reese, Mark D. Semon, and Robin B. S. Brooks, contains answers and solutions to all end-of-chapter problems in the text.

ASSESSMENT TOOLS AND MATERIALS

Test Items for University Physics, by Frank Steckel, includes a copy of the test questions provided electronically in *Thomson World Class Learning™ Testing Tools*, Review Exercise Worksheets, and answers to the test item questions. The notation of the test items carefully follows that of the main text.

Thomson World Class Learning™ Testing Tools is a fully integrated suite of test creation, delivery, and classroom management tools. This invaluable set of tools includes World Class Test, Test Online, and World Class Manager software. World Class Test allows instructors to create dynamic questions that regenerate the values of variables and calculations between multiple versions of the same test. Tests, practice tests, and quizzes created in World Class Test can be delivered via paper, diskette or local hard drive, LAN (Local Area Network), or the Internet. All testing results can then be integrated into a complete classroom management tool with scoring, gradebook, and reporting capabilities.

With World Class Test, instructors can create a test from an existing bank of objective questions including multiple-choice, true/false, and matching questions or instructors can also easily edit existing questions and add their own questions and graphics. The online system can automatically score *objective* questions. *Subjective* essay and fill-in-the-blank questions that the instructor evaluates can also be added. Results can be scored, merged with final test results, and entered automatically into the gradebook.

Using *World Class Course*, you can quickly and easily create and update a web page specifically for a course or class. Post your own course information, office hours, lesson information, assignments, sample tests, and links to rich web content.

PRESENTATION TOOLS AND ONLINE RESOURCES

Transparencies in full color include more than 200 illustrations from the text, enlarged for use in the classroom and lecture halls.

CNN Physics Video, produced by Turner Learning, can stimulate and engage your students by launching a lecture, sparking a discussion, or demonstrating an application. Each physics-related segment from recent CNN broadcasts clearly demonstrates the relevancy of physics to everyday life.

With *Brooks/Cole's PhysicsLink*, a cross-platform CD-ROM, creating lectures has never been easier. Using multi-tiered indexing, search capabilities, and a comprehensive resource bank that includes glossary, graphs, tables, illustrations, photographs, and animations, instructors can conduct a quick search to incorporate these materials into presentations and tests. And, any *PhysicsLink* file can be posted to the web for easy student reference.

WebAssignOnline homework, a versatile, web-based homework delivery system, saves time grading and recording homework assignments and provides students with individual practice and instant feedback on their work. It delivers, collects, grades, and records customized homework assignments over the Internet. Assignments can be customized so each student can receive a unique question to solve. Access to *WebAssign* is secured by passwords and each student has access only to his or her record. *WebAssign* ©1998–99 by North Carolina State University.

ACKNOWLEDGMENTS

A wise man will hear, and will increase learning;
and a man of understanding shall attain unto wise counsels.

Proverbs 1:5

My interest in physics was sparked long ago by two gifted mentors at Middlebury College: Benjamin F. Wissler, whose wonderfully friendly Cheshire-cat-like grin I still can see today, and Chung-Ying Chih, whose appreciation of elegance was always apparent in his approach to physics. Their excitement for the subject was contagious and their rigor and demands upon their students legendary. Subsequent mentors included Herman Z. Cummins (then at The Johns Hopkins University, now at CUNY) and my colleagues at Washington and Lee University and elsewhere, gentlemen and gentlewomen whose gifts for teaching and research continue to be admirable role models, worthy of emulation.

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The reviewers of this manuscript are listed alphabetically below. Their thorough and insightful reading and frank and honest critiques were invaluable to the creation of this book.

Royal G. Albridge, Vanderbilt University
C. David Andereck, Ohio State University
Gordon Aubrecht, Ohio State University
Rene Bellwied, Wayne State University
Van Bluemel, Worcester Polytechnic Institute
Neal M. Cason, University of Notre Dame
Kenneth C. Clark, University of Washington
Richard M. Heinz, University of Indiana
Daniel G. Montague, Willamette University
Richard Muirhead, University of Washington
Richard Ditteon, Rose-Hulman Institute of Technology
Charles Scheer, University of Texas, Austin
Mark Semon, Bates College
William S. Smith, Boise State University
Karl Trappe, University of Texas, Austin
Ronald E. Zammit, California Polytechnic State University

Two reviewers deserve special accolades. Their dedication went well beyond the call.

Professor Kenneth C. Clark meticulously read and reread, critiqued and recritiqued *every* draft of the manuscript from its humblest beginnings, making innumerable suggestions for clean and clever ways to elucidate many phenomena. Special thanks also go to Professor Mark Semon, whose attention to detail in his reviews was similar: insightful, thoughtful, and brimming with constructive suggestions.

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Clearly, any errors remaining within the text are my responsibility. I would be very grateful to readers who bring errors of any kind to my attention [reeser@wlu.edu]. I truly welcome all your comments, critiques, and suggestions.

Shalom aleichem

PREFACE TO STUDENTS

The supreme task of the physicist is to arrive at those universal elementary laws from which the cosmos can be built up by pure deduction. There is no logical path to these laws; only intuition, resting upon sympathetic understanding of experience, can reach them.

*Albert Einstein (1879–1955)**

What a wonderful and exciting privilege it is to study and to teach physics! Physics is the bedrock of all the sciences and technology. Whether it be chemistry, geology, biology, medicine, engineering, or astronomy, our descriptions of nature involve understanding how particles move and interact individually and collectively. This understanding is the fundamental domain of physics. So, if you want to become a scientist, engineer, doctor, or a natural philosopher, or simply to understand nature at its most fundamental level as an intelligent citizen-scientist, you need to begin with a voyage through the foundations of physics.

The mission of this text is

- to present the subject in a logical, clear, and comprehensible style;
- to stress how *little* needs to be known in order to understand as much as possible;
- to recognize that many aspects of physics, while quantifiable, remain fundamentally abstract and mysterious—we do not have the answers to many profound questions; and
- to lighten the stress over technical gobbledygook with occasional humor.

I hope this book conveys the excitement of a fascinating search for a fundamental understanding of nature. The discipline of physics is, after all, the observation, explanation, and integration into a conceptual whole of as much as we can see, perceive, and infer during our all-too-short intellectual rendezvous with this amazing universe.

The beauty and coherence of physics may be obvious to professors, but may be less clear to you, our students, since physics likely seems less romantic than the beauty of the starlit sky. Understanding the celestial dances of the firmament, though, really is physics. So is understanding why the night sky is dark, why clouds are white, why the sky is blue, why bubbles appear in a bottle of beer or a glass of champagne, and what drives the wondrous biochemical processes that make life itself possible and gives us the opportunity to wonder at the beauty, not only of each other, but also of the natural world surrounding us.

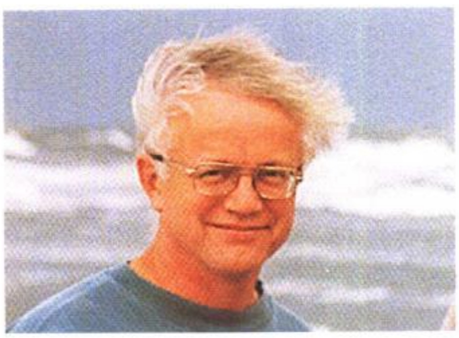
We have an exciting time of study ahead. From a practical viewpoint, careful and thoughtful multiple readings of the text material are encouraged. Your first reading might omit the example problems in order to gain a conceptual overview of the material sufficient to address the Questions; a second reading then can include sufficient examples (particularly the Strategic Examples) for you to gain the necessary familiarity to approach the Problems.

In the conceptual development, examples, and problems, great emphasis is placed on the choices you have to make and the consequences of those choices. This is designed to gradually build confidence in your ability to tackle new and different situations. It will also teach you to be alert for the unexpected, or unanticipated result. Most significant discoveries in science begin with simply noticing something unexpected or peculiar. "What's that?" has led to many a significant "Aha!" in the history of science and technology.

*"Principles of Research," *Ideas and Opinions by Albert Einstein*, edited by Carl Seelig (Crown Publishers, New York, 1954), page 226.

ABOUT THE AUTHOR

Professor Reese teaches physics and astronomy at Washington and Lee University in Lexington, Virginia. He received his undergraduate degree in physics from Middlebury College and his Ph.D. in physics from The Johns Hopkins University. He has been teaching introductory physics, astronomy, and various advanced physics courses for almost 30 years. He also has performed consulting research on the interaction of visible and microwave electromagnetic radiation with matter at the Naval Research Laboratory in Washington, D.C., and has been a Visiting Fellow at University College, Oxford, during several sabbaticals.



FUNDAMENTAL PHYSICAL CONSTANTS

Quantity	Symbol	Value to use in calculations in this text	More precise value
Atomic mass unit	u	1.66×10^{-27} kg	$1.660\,540 \times 10^{-27}$ kg
Avogadro's number	N_A	6.02×10^{23} mol^{-1}	$6.022\,137 \times 10^{23}$ mol^{-1}
Boltzmann's constant	k	1.381×10^{-23} J/K	$1.380\,658 \times 10^{-23}$ J/K
Electron mass	m_e	9.11×10^{-31} kg	$9.109\,389 \times 10^{-31}$ kg
Electron-volt	eV	1.602×10^{-19} J	$1.602\,177 \times 10^{-19}$ J
Fundamental charge	e	1.602×10^{-19} C	$1.602\,177 \times 10^{-19}$ C
Gas constant	R	8.315 J/(mol·K)	8.314 51 J/(mol·K)
Gravitational constant	G	6.67×10^{-11} N·m^2/kg^2	$6.672\,59 \times 10^{-11}$ N·m^2/kg^2
Neutron mass	m_n	1.67×10^{-27} kg	$1.674\,928 \times 10^{-27}$ kg
Permeability of free space	μ_0	$4\pi \times 10^{-7}$ T·m/A	exact
	$\frac{\mu_0}{4\pi}$	10^{-7} T·m/A	exact
Permittivity of free space	ϵ_0	8.854×10^{-12} C^2/(N·m^2)	$8.854\,187\,817 \times 10^{-12}$ C^2/(N·m^2)(exact)
	$\frac{1}{4\pi\epsilon_0}$	9.00×10^9 N·m^2/C^2	
Planck's constant	h	6.626×10^{-34} J·s	$6.626\,075 \times 10^{-34}$ J·s
	$\hbar \equiv \frac{h}{2\pi}$	1.055×10^{-34} J·s	$1.054\,573 \times 10^{-34}$ J·s
Proton mass	m_p	1.67×10^{-27} kg	$1.672\,623 \times 10^{-27}$ kg
Speed of light in vacuum	c	3.00×10^8 m/s	$2.997\,924\,58 \times 10^8$ m/s (exact)

FREQUENTLY USED PHYSICAL DATA

Bohr radius	$a_0 = 0.529 \times 10^{-10}$ m
Magnitude of the local acceleration due to gravity near the surface of the Earth	$g = 9.81$ m/s^2
Density of air (20 °C and 1 atm)	1.20 kg/m^3
Density of water (20 °C and 1 atm)	1.00×10^3 kg/m^3
Hydrogen ground state energy	−13.6 eV
Latent heat of vaporization of water	22.57×10^5 J/kg
Latent heat of fusion of water	3.335×10^5 J/kg
Solar constant	1.36 kW/m^2
Solar luminosity	3.83×10^{26} W
Speed of sound in air (20 °C and 1 atm)	343 m/s
Standard atmospheric pressure (1 atm)	1.013×10^5 Pa

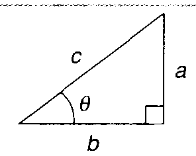
GEOMETRIC FIGURES

Circle of radius r	area = πr^2	perimeter = $2\pi r$
Sphere of radius r	area = $4\pi r^2$	volume = $\frac{4}{3}\pi r^3$
Triangle	area = $\frac{1}{2}$ (base)(height)	
Right circular cylinder of radius r and height h	lateral area = $2\pi r h$	volume = $\pi r^2 h$
Right circular cone of base radius r and height h	lateral area = $\pi r\,[r^2 + h^2]^{1/2}$	volume = $\frac{1}{3}\pi r^2 h$

ALGEBRA AND TRIGONOMETRY

Quadratic equation: $ax^2 + bx + c = 0$ $\qquad x = \dfrac{-b + \sqrt{b^2 - 4ac}}{2a}$

Right triangle:



Pythagorean theorem: $c^2 = a^2 + b^2$

$\sin\theta = \dfrac{a}{c}$

$\cos\theta = \dfrac{b}{c}$

$\tan\theta = \dfrac{a}{b}$

$$\sin(\alpha \pm \beta) = \sin\alpha\cos\beta \pm \cos\alpha\sin\beta$$

$$\cos(\alpha \pm \beta) = \cos\alpha\cos\beta \mp \sin\alpha\sin\beta$$

$$\cos\alpha + \cos\beta = 2\cos\left(\frac{\alpha + \beta}{2}\right)\cos\left(\frac{\alpha - \beta}{2}\right)$$

COMMONLY USED PREFIXES FOR POWERS OF 10

Power	*Prefix*	*Abbreviation*	*Example*
10^{-18}	atto-	a	
10^{-15}	femto-	f	
10^{-12}	pico-	p	picofarad (pF)
10^{-9}	nano-	n	nanometer (nm)
10^{-6}	micro-	μ	micrometer (μm)
10^{-3}	milli-	m	millimeter (mm)
10^{-2}	centi-	c	centimeter (cm)
10^{-1}	deci-	d	decibel (dB)

Power	*Prefix*	*Abbreviation*	*Example*
10^{1}	deka-	da	(rarely used in physics)
10^{2}	hecto-	h	(rarely used in physics)
10^{3}	kilo-	k	kilogram (kg)
10^{6}	mega-	M	megawatt (MW)
10^{9}	giga-	G	gigajoule (GJ)
10^{12}	tera-	T	
10^{15}	peta-	P	
10^{18}	exa-	E	

CONVERSION FACTORS OCCASIONALLY NEEDED

Length

1 inch = 2.54 cm

1 mile = 1.653 km

1 light-year = 9.461×10^{15} m

1 AU = 1.496×10^{11} m

Time

1 d = 8.6400×10^{4} s

1 y = 3.156×10^{7} s

Speed

1 km/h = 0.2778 m/s

Volume

1 m^3 = 1000 liters

Energy

1 eV = 1.602×10^{-19} J

Pressure

1 atm = 1.013×10^{5} Pa