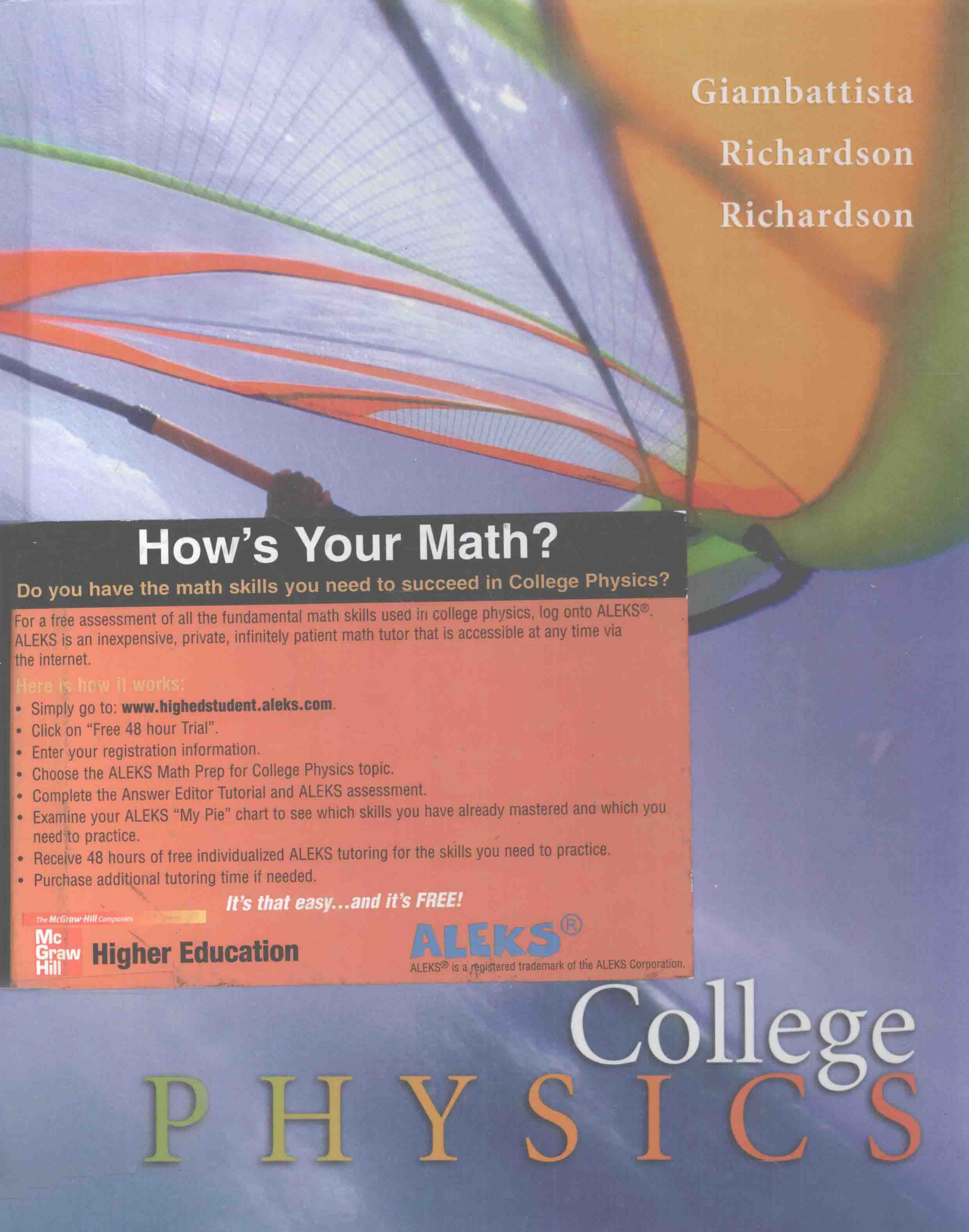


Giambattista
Richardson
Richardson

College PHYSICS

College PHYSICS

Alan Giambattista
Cornell University

Betty McCarthy Richardson
Cornell University

Robert C. Richardson
Cornell University

Mc Graw Hill Higher Education

Boston Burr Ridge, IL Dubuque, IA Madison, WI New York San Francisco St. Louis
Bangkok Bogotá Caracas Kuala Lumpur Lisbon London Madrid Mexico City
Milan Montreal New Delhi Santiago Seoul Singapore Sydney Taipei Toronto

COLLEGE PHYSICS

Published by McGraw-Hill, a business unit of The McGraw-Hill Companies, Inc., 1221 Avenue of the Americas, New York, NY 10020.

This book is printed on acid-free paper.

International 1 2 3 4 5 6 7 8 9 0 VNH/VNH 0 9 8 7 6 5 4 3
Domestic 1 2 3 4 5 6 7 8 9 0 VNH/VNH 0 9 8 7 6 5 4 3

ISBN 0–07–052407–6
ISBN 0–07–121462–3 (ISE)

Publisher: *Kent A. Peterson*
Sponsoring editor: *Daryl Bruflodt*
Developmental editor: *Mary E. Haas*
Marketing manager: *Debra B. Hash*
Lead project manager: *Jill R. Peter*
Senior production supervisor: *Laura Fuller*
Senior media project manager: *Stacy A. Patch*
Media technology producer: *Jeff Huettman*
Design manager: *Stuart Paterson*
Cover/interior designer: *Jamie E. O'Neal*
Cover image: *Stone*
Lead photo research coordinator: *Carrie K. Burger*
Photo research: *Karen Pugliano*
Supplement producer: *Brenda A. Ernzen*
Compositor: *Precision Graphics*
Typeface: *10/12 Times Roman*
Printer: *Von Hoffmann Corporation*

The credits section for this book begins on page 1137 and is considered an extension of the copyright page.

Library of Congress Cataloging-in-Publication Data

Giambattista, Alan.
College physics / Alan Giambattista, Betty McCarthy Richardson, Robert C. Richardson. — 1st ed.
p. cm.
Includes index.
ISBN 0–07–052407–6 (set : acid-free paper) — ISBN 0–07–253724–8 (v. 1 : acid-free paper) — ISBN 0–07–253725–6 (v. 2 : acid-free paper)
1. Physics. I. Richardson, Betty McCarthy. II. Richardson, Robert C. (Robert Coleman), 1937–. III. Title.

QC21.3 .G53 2004
530—dc21 2002038915
CIP

INTERNATIONAL EDITION ISBN 0–07–121462–3

www.mhhe.com

LIST OF SELECTED APPLICATIONS

Biology/Life Science

Forces supporting a water strider, Section 2.2
Forces on bird in air, Section 2.4
Function of tendons in the body, Section 2.7
Force exerted by deltoid muscle, Examples 4.3, 8.10
Traction applied to a leg, Example 4.5
Seagull dropping a clam, Section 4.5
Energy conversion in a jumping cricket, Section 6.6
Energy conversion in animal jumping, Section 6.6, Example 6.10
Flexor versus extensor muscles, Section 8.5
Forces on the human spine during heavy lifting, Section 8.5
Sphygmomanometer and blood pressure, Section 9.5
Floating and sinking of fish and animals, Example 9.8
Speed of blood flow, Example 9.9
Air circulation in underground burrows, Section 9.8
Arterial blockage, Example 9.12
Surface tension of alveoli in the lungs, Example 9.14
Tension and compression in bone, Example 10.2
Size limitations on organisms, Section 10.3
Comparison of walking speeds for various creatures, Example 10.10
Sound waves from a songbird, Example 12.2
Human ear, Section 12.5
Echolocation of bats and dolphins, Section 12.10
Medical applications of ultrasound, ultrasonic imaging, Section 12.10
Evolutionary advantages of warm-blooded versus cold-blooded animals, Section 13.7
Diffusion of oxygen into the bloodstream, Example 13.10
Using ice to protect buds from freezing, Section 14.5
Thermal radiation from the human body, Example 14.15
Electrolocation in fish, Section 16.4
Transmission of nerve impulses, Section 17.2, Example 17.11
Electrocardiogram (EKG), Section 17.2
Electroencephalogram (EEG), Section 17.2
Defibrillator, Example 17.12, Section 18.11
Magnetotactic bacteria, Section 19.1
Electromagnetic blood flow meter, Section 19.5
Magnetoencephalography, Section 20.3
Thermograms of the human body, Section 22.4
Fluorescence, Section 22.4
X-rays in medicine and dentistry, CAT scans, Section 22.4, Example 27.4
Navigation of bees, Section 22.8
Endoscope, Section 23.4
Human eye, Section 24.3
Correcting myopia/hyperopia, Section 24.3, Examples 24.4, 24.5
Iridescent colors in butterfly wings, Section 25.3
Resolution of the human eye, Section 25.8
Electron microscopes, Section 28.3
Laser surgery, Section 28.9
Radiocarbon dating, Section 29.4
Biological effects of radioactivity, Section 29.5
Radioactive tracers in medical diagnosis, Section 29.5
Positron emission tomography (PET) scans, Section 29.5
Radiation therapy, Section 29.5
Gamma knife radiosurgery, Section 29.5

Chemistry

Collision between krypton atom and water molecule, Example 7.10
Change of reaction rate with temperature, Example 13.8
Polarization of charge in water, Section 16.1
Current in electrolytes, Section 18.1
Spectroscopic analysis of elements, Section 27.6
Electron orbitals, electron configurations of atoms, Section 28.7
Periodic Table, Section 28.7

Geology/Earth Science

Forces on a submersible, Example 2.1
Angular speed of Earth, Example 5.1
Thunderclouds and lightning, Example 17.1, Section 17.6
Earth's magnetic field, Section 19.1, Examples 19.1, 19.2
Intensity of sunlight reaching the Earth, Example 22.6
Colors of the sky during the day and at sunset, Section 22.8
Rainbows, Section 23.3
Cosmic rays, Examples 26.2, 26.4
Radioactive dating of geologic formations, Section 29.4
Neutron activation analysis of geological objects, Section 29.5

Astronomy/Space Science

Spacecraft to Mars, Unit conversions, Section 1.5
Detection of extrasolar planets, Section 2.3
Speed of Hubble Telescope orbiting the Earth, Example 5.8
Kepler's laws of planetary motion, Sections 5.4, 8.8
Orbit of geostationary satellite, Examples 5.9, 6.7
Apparent weightlessness of orbiting astronauts, Section 5.7
Work on an orbiting satellite, Section 6.2
Escape speed from Earth, Example 6.9

Architecture

Technology/Machines

Transportation

Sports

Everyday Life

PREFACE

College Physics is intended for a two-semester college course in introductory physics using algebra and trigonometry. Our main goals in writing this book are

- To present the basic concepts of physics that students need to know for later courses and future careers,
- To emphasize that physics is a tool for understanding the real world, and
- To teach transferable problem-solving skills that students can use throughout their lives.

We have kept these goals in mind while developing the main themes of the book.

COMPREHENSIVE COVERAGE

Students should be able to get the whole story from the book. The manuscript was tested for five semesters in a self-paced course, where students *must* rely on the textbook as their primary learning resource. Nonetheless, completeness and clarity are equally advantageous when the book is used in a more traditional classroom setting. Over a dozen other class tests have shown that *College Physics* frees the instructor from having to try to "cover" everything and from filling in the gaps left by the text. The instructor can then tailor class time to the students' needs, whether it be going over particularly difficult concepts, working through examples, engaging the students in cooperative learning activities, describing applications, or presenting demonstrations.

INTEGRATING CONCEPTUAL PHYSICS INTO A QUANTITATIVE COURSE

Some students approach introductory physics with the idea that physics is just the memorization of a long list of equations and the ability to plug numbers into those equations. We want to help students see that a relatively small number of basic physics concepts are applied to a wide variety of situations. In our presentation, based on years of teaching this course, we blend conceptual understanding with analytical skills, using plain language with simple mathematics throughout the book. In our experience, this approach anticipates many of the conceptual difficulties that students may have.

Physics education research has shown that students do not automatically acquire conceptual understanding; the concepts must be explained and the students given a chance to grapple with them. To that end, we include many **Conceptual Examples** and **Conceptual Practice Problems** in the text and a selection of **Conceptual Questions** and **Multiple Choice Questions** at the end of each chapter.

INTRODUCING CONCEPTS INTUITIVELY

We introduce key concepts and quantities in an informal way by establishing why the quantity is needed, why it is useful, and why it must be defined precisely. Then we make a transition from the informal, intuitive idea to a formal definition and name. We find that concepts motivated in this way are easier for students to grasp and remember than are concepts introduced by seemingly arbitrary, formal definitions.

For example, in Chapter 8, the idea of rotational inertia emerges in a natural way from the concept of rotational kinetic energy. Students can understand that a rotating rigid body has kinetic energy due to the motion of its particles. We discuss why it is useful to be able to write this kinetic energy in terms of a single quantity common to all the particles, rather than as a sum involving particles with many different speeds. Using this approach, the definition of rotational inertia is motivated; students understand why it is

> *"I think chapter 8 is particularly well-written. Rotational motion, magnetism, and AC circuits spring to mind as the most notoriously difficult subjects to teach in this course. The authors have chosen a number of excellent biomechanical examples in chapter 8 and this chapter's presentation alone might persuade some lecturers to switch texts."*—Dr. Nelson E. Bickers, University of Southern California

defined the way it is. Then, equipped with an understanding of rotational inertia, students are better prepared for the concept of torque.

We avoid as much as possible presenting definitions or formulas without any motivation. When an equation cannot be derived using algebra and trigonometry, we at least indicate where the equation comes from or give a plausibility argument. For example, Section 9.9 introduces Poiseuille's law with two identical pipes in series to show why the volume flow rate must be proportional to the pressure drop per unit length. Then we discuss why $\Delta V/\Delta t$ is proportional to the fourth power of the radius (rather than to R^2, as for an ideal fluid).

Similarly, we have found that the definitions of the displacement and velocity vectors seem arbitrary and counterintuitive to students if introduced without any motivation. Therefore, we precede any discussion of kinematic quantities with an introduction to Newton's laws, so students know that forces determine how the state of motion of an object changes. Then, when we define the kinematic quantities to give a precise definition of acceleration, we can apply Newton's second law quantitatively to see how forces affect the motion. We give particular attention to laying the groundwork for a concept when its name is a common English word such as *velocity* or *work.*

HELPING STUDENTS SEE THE RELEVANCE OF PHYSICS IN THEIR LIVES

Students in an introductory college physics course have a wide range of backgrounds and interests. We stimulate interest in physics by relating the principles to applications relevant to students' lives. We appeal to topics familiar to students and in line with their interests.

The text, examples, and end-of-chapter problems draw from the everyday world, from familiar technological applications, and from other fields such as biology, medicine, archaeology, astronomy, sports, environmental science, and geophysics. Applications in the text are marked with an icon in the margin , **Making The Connection**.

In addition, the **Physics at Home** experiments give the students an opportunity to explore and see physics principles operate in their everyday lives. These activities are chosen for their simplicity and for the effective demonstration of physics principles. Each **Chapter Opener Vignette** is designed to capture student interest and maintain it through the chapter. The question asked in each opener is answered somewhere in the chapter.

WRITTEN IN CLEAR AND FRIENDLY STYLE

We have kept the writing down-to-earth and conversational in tone—the kind of language an experienced teacher uses when sitting at a table working one-on-one with a student. We believe students will find the book pleasant to read, informative, accurate without seeming threatening, and filled with analogies that make abstract concepts easier to grasp. We want students to feel confident that they can learn by studying the textbook.

While learning correct physics terminology is essential, we avoid all *unnecessary* jargon—terminology that just gets in the way of the student's understanding.

PROBLEM-SOLVING APPROACH

Problem-solving skills are central to an introductory physics course. We illustrate these skills in the example problems. Lists of problem-solving strategies are sometimes useful; we provide such strategies when appropriate. However, the most elusive skills—perhaps the most important ones—are subtle points that defy being put into a neat list. To develop real problem-solving expertise, students must learn how to think critically and analytically. Problem solving is a multidimensional, complex process; an algorithmic approach is not adequate to instill real problem-solving skills.

> *"The major strength of this text is its approach, which makes students think out the problems, rather than always relying on a formula to get an answer. The way the authors encourage students to investigate whether the answer makes sense, and compare the magnitude of the answer with common sense is good also."*—Dr. Jose D'Arruda, University of North Carolina, Pembroke

Strategy We begin each example with a discussion—in language that the students can understand—of the **Strategy** to be used in solving the problem. The strategy illustrates the kind of analytical thinking students must do when attacking a problem: How do I decide what approach to use? What laws of physics apply to the problem and which of them are *useful* in this solution? What clues are given in the statement of the question? What information is implied rather than stated outright? If there are several valid approaches, how do I determine which is the most efficient? What assumptions can I make? What kind of sketch or graph might help me solve the problem? Is a simplification or approximation called for? If so, how can I tell if the simplification is valid? Can I make a preliminary estimate of the answer? Only after considering these questions can the student effectively solve the problem.

"I understood the math, mostly because it was worked out step-by-step, which I like."—student, Bradley University
"The math was really clear. I was impressed with how easy the math and steps involved were to understand."—student, Bradley University

"The 'Strategy & Discussion' in each example were extremely helpful in understanding the ideas."—student, Houston Community College

Solution Next comes the detailed **Solution** to the problem. Explanations are intermingled with equations and step-by-step calculations to help the student understand the approach used to solve the problem. We want the student to be able to follow the mathematics without wondering, "Where did that come from?"

Discussion The numerical or algebraic answer is not the end of the problem; our examples end with a **Discussion**. Students must learn how to determine whether their answer is consistent and reasonable by checking the order of magnitude of the answer, comparing the answer to a preliminary estimate, verifying the units, and doing an independent calculation when more than one approach is feasible. When there are several different approaches, the Discussion looks at the advantages and disadvantages of each approach. We also discuss the implications of the answer—what can we learn from it? We look at special cases and look at "what if" scenarios. The Discussion sometimes generalizes the problem-solving techniques used in the solution.

Practice Problem After each Example, a **Practice Problem** gives students a chance to gain experience using the same physics principles and problem-solving tools. By comparing their answers to those provided at the end of each chapter, they can gauge their understanding and decide whether to move on to the next section.

Our many years of experience in teaching college physics in a one-on-one setting has enabled us to anticipate where we can expect students to have difficulty. In addition to the consistent problem-solving approach, we offer several other means of assistance to the student throughout the text. A boxed problem-solving strategy gives detailed information on solving a particular type of problem, while an icon for problem-solving tips draws attention to techniques that can be used in a variety of contexts. A hint in a worked example or end-of-chapter problem provides a clue on what approach to use or what simplification to make. A warning icon emphasizes explanations that clarify possible points of confusion or common student misconceptions.

An important problem-solving skill that many students lack is the ability to extract information from a graph or to sketch a graph without plotting individual data points. Graphs often help students visualize physical relationships more clearly than they can do with algebra alone. We emphasize the use of graphs and sketches in the text, in worked examples, and in the problems.

USING APPROXIMATION, ESTIMATION, AND PROPORTIONAL REASONING *College Physics* is up front about the constant use of simplified models and approximations in solving physics problems. One of the most difficult aspects of problem solving that students need to learn is that some kind of simplified model or approximation is usually required. We discuss how to know when it is reasonable to ignore friction or air resistance, treat *g* as constant, ignore viscosity, treat a charged object as a point charge, or ignore diffraction. A brief discussion of air resistance and terminal velocity in Chapter 3 enables us to discuss when it is reasonable to ignore air resistance—and also to show students that physics can account for these other effects.

Some Examples and Problems require the student to make an estimate—a useful skill both in physics problem solving and in many other fields. Similarly, we teach proportional reasoning as not only an elegant shortcut but also as a means to understanding patterns. We frequently use percentages and ratios to give students practice in using and understanding them.

SHOWCASING AN INNOVATIVE ART PROGRAM

Throughout the book we emphasize the value of drawing diagrams to help visualize and understand physical situations. We live up to our own advice by including many drawings, using color to distinguish different kinds of physical quantities so students can better see what concepts are important in each situation.

To help show that physics is more than a collection of principles that explain a set of contrived problems, in every chapter we have developed several innovative **Showcase Illustrations** to bring to life the connections between physics concepts and the complex ways in which they are applied. We believe these illustrations, with subjects ranging from three-dimensional views of electric field lines to the biomechanics of the human body and from representations of waves to the distribution of electricity in the home, will help students see the power and beauty of physics. We also provide many photographs to convey the application of physics to the real world and to help motivate many topics.

INNOVATIVE ORGANIZATION

There are a few places where, for pedagogical reasons, the organization of our text differs from that of most textbooks. The most significant reorganization is in the treatment of forces and motion. In *College Physics,* the central theme of Chapters 2–4 is *force.* Kinematics is woven into the fabric of the three force chapters as a tool to understand how forces affect motion. Overall, we spend less time on kinematics and more time on forces. This approach has these advantages:

- The first few chapters in any text set up student expectations that are hard to change later. If the course starts with a series of definitions of the kinematic quantities, with no explanation of *why* we are interested in those quantities, students may see physics as a series of equations to memorize and manipulate. Similarly, it is not a good precedent for students to learn all of the vector techniques at the outset when they are not yet needed.
- We explain to students that we develop the kinematic concepts so we can understand the effect of a net force on the motion of an object. Newton's second law is the key reason why we need a precise definition of acceleration; to define acceleration requires that we first define displacement and velocity. If the definitions of these quantities are imprecise, we cannot hope to understand how forces change the state of motion of an object. We have found that laying out this clear program at the start of the course helps students realize that in physics, physical concepts determine understanding, not mathematics.
- Learning kinematics first may suggest to students that physics is not connected to the real world. If they are told that objects all fall with the same acceleration—which they know from experience to be false—they learn not to trust the principles they're learning. With an understanding of forces and Newton's laws, *College Physics* enables the student to learn that constant acceleration is an approximation and to learn how to judge when that approximation is reasonable.
- A gradual introduction to vectors lets students acquire basic vector skills before moving on to more difficult ideas. We spread the vector material over three chapters, introducing vector techniques *as needed,* so students are not overloaded with formalism. We emphasize understanding how the physical vector quantities behave and can be analyzed, so that students are not required to learn the operations of an abstract mathematical entity before they have any inkling of how essential they are to problem solving in physics. It is our experience that by the time students reach Chapter 4, on forces and nonuniform motion in two dimensions, they have already attained a high level of proficiency with vector techniques (and with the conceptual framework of Newton's laws).

"I am thoroughly delighted to see a text which presents Newton's laws before kinematics. This in my opinion is an intuitively better approach for the students. I believe it is better to deal with why things move before we attempt to quantitatively describe the resulting motion. . . . Compared to the text we have been using, this approach is better."—Dr. Kelly Roos, Bradley University

"It was easier to understand these ideas since we came from reading about Newton's laws."—student, Bradley University

"I was concerned about having Newton's laws before kinematics until I read the chapters. After reading the chapters I think that this ordering is preferable to the more traditional order. . . . The approach that is taken with Newton's laws, introducing them at the beginning and spreading them out throughout the next three chapters is also very good. Understanding Newton's laws is one of the most difficult things that the students have to do in this class, and teaching them over and over again over a period of time is the best way to do it. I really liked the approach here."—Dr. Grant Hart, Brigham Young University

- We use correct vector terminology and methods from the very beginning. Even in one dimension, displacements, velocities, and accelerations are treated as vector quantities. Chapter 2 starts with the graphical addition of one-dimensional vectors. Chapter 3 introduces subtraction and component notation for one-dimensional vectors. For example, we write "$v_x = -5$ m/s" rather than "$v = -5$ m/s" when we are talking about a velocity component; we carefully distinguish components from magnitudes. Thus, the students carry over everything they learned about vectors in one dimension to two dimensions, without any change of notation. Some of our class testers report fewer students struggling with the concept of vector components using *College Physics* compared to their previous textbook.
- We begin in Chapter 2 with Newton's laws of motion so the students can build a solid conceptual framework in situations where the mathematics is simple. If forces were not introduced until Chapter 4, the students would have much less time to overcome conceptual difficulties associated with Newton's laws and would have much less practice applying them.

ACCURACY ASSURANCE

The authors and the publisher acknowledge the fact that inaccuracies can be a source of frustration for both the instructor and students. Therefore, throughout the writing and production of this textbook we have worked diligently to eliminate errors. We would like to describe the process used to assure the accuracy of this textbook.

Dr. Larry Rowan, of the University of North Carolina, checked the accuracy of all textual examples, practice problems and solutions, and end-of-chapter questions and problems in the second draft of the manuscript. Corrections were made to the final draft manuscript by the authors.

Dr. Richard Heinz, of Indiana University, and Dr. Marllin Simon, of Auburn University, then independently checked the accuracy of all textual examples and practice problems and solutions and worked all end-of-chapter questions and problems in the final draft of the manuscript.

Bill Fellers of Laurel Technology also conducted an independent accuracy check and worked all end-of-chapter questions and problems in the final draft of the manuscript. He then coordinated his efforts with Dr. Heinz, Dr. Simon, and the authors to resolve any discrepancies to ensure the accuracy of not only the text, but also the end-of-book answer section and the solutions manual. Corrections were then made to the manuscript before it was typeset.

The page proofs of the text were double-proofread against the manuscript to ensure the correction of any errors introduced when the manuscript was typeset. The textual examples, practice problems and solutions, end-of-chapter questions and problems, and problem answers were accuracy checked by Laurel Technology again at the page proof stage after the manuscript was typeset. This last round of corrections was then cross-checked against the solutions manual.

TO THE STUDENT: HOW TO USE THIS TEXTBOOK

Welcome! We hope that you enjoy your physics course. While studying physics does require hard work, in writing this book we have tried to remove the obstacles that sometimes make introductory physics unnecessarily difficult. We have also tried to show the beauty inherent in the principles of physics and how these principles are manifest all around you.

In our years of teaching experience, we have found that studying physics is a skill that must be learned. It's much more effective to *study* a physics textbook, which involves *active participation* on your part, rather than to read through passively. Even though active study takes more time initially, in the long run it will *save* you time; you learn more in one active study session than in three or four superficial readings. Here are some suggestions to help you get the most out of your study:

- Study the text *before* attending class on the same topic. Knowing what's in the book helps you take notes selectively rather than scrambling to write everything down. You'll be able to absorb more of the subtleties and difficult points from class. You'll also have some good questions to ask your instructor.

- Don't try to read an entire chapter in one sitting; study one or two sections at a time. It's difficult to maintain your concentration in a long session with so many new concepts and skills to learn.
- As you study, take particular note of these elements:

  Boxed laws, rules, and equations indicate the most important and central concepts.

   indicates a warning about a common student misconception or point of confusion.

  indicates a helpful problem-solving tip.

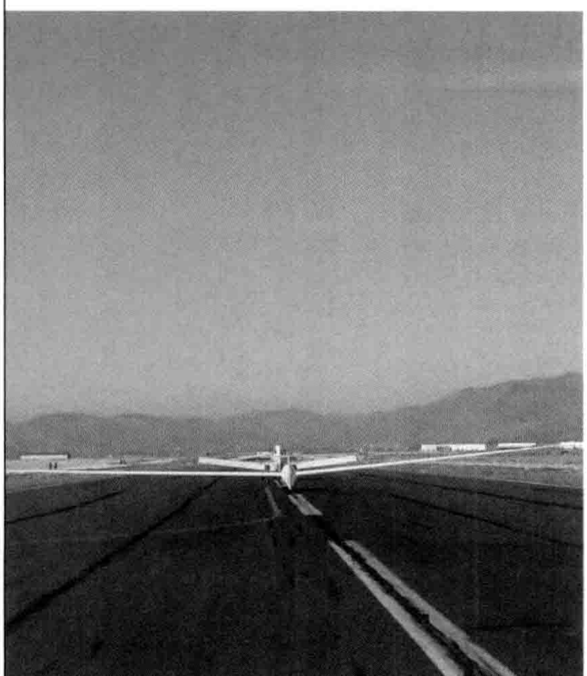
  Boxed problem-solving strategies give detailed information on solving a particular type of problem.
- When you come to an Example, pause after you've read the problem. Think about the strategy you would use to solve the problem. See if you can work through the problem on your own. Now study the Strategy, Solution, and Discussion in the textbook. Sometimes you will find that your own solution is right on the mark; if not, you can focus your attention on the place where you got stuck or any mistakes you may have made.
- Work the Practice Problem after each Example to practice applying the physics concepts and problem-solving skills you've just learned. Check your answer with the one given at the end of the chapter. If your answer isn't correct, review the previous section in the textbook to try to find your mistake.
- Take time to study the figures and graphs carefully.
- Find a study partner and get together regularly. Go over the difficulties either of you may be having. Take turns explaining things to each other—you learn a tremendous amount when you teach someone else. Compare your solutions to the Practice Problems. Discuss some of the Conceptual Questions from the end of the chapter.
- Try the Physics at Home experiments. They reinforce key physics concepts and help you see how these concepts operate in the world around you.
- Write your *own* chapter summary or outline and then compare it with the summary provided at the end of the chapter. This will help you identify the most important and fundamental concepts in each chapter.

We hope that these suggestions will help you get the most out of *College Physics*. We have spent many years working with students, both in the classroom and one-on-one in a self-paced course. We wrote this book so you could benefit from our experience as we carefully address the points that have caused difficulties for our students in the past. We also wish to share with you some of the pleasure and excitement we have found in learning about the physical laws that govern our world.

GUIDED TOUR

Chapter 3

Forces and Motion Along a Line



A sailplane (or "glider") is a small, unpowered, high-performance aircraft. A sailplane must be initially towed a few thousand feet into the air by a small airplane, after which it relies on regions of upward-moving air such as thermals and ridge currents to ascend further. Suppose a small plane requires about 120 m of runway to take off by itself. When it is towing a sailplane, how much more runway does it need?

Chapter Opener

Each ***Chapter Opener*** includes a chapter opening photo and vignette designed to capture student interest and maintain it throughout the chapter. The vignette describes the situation shown in the photo and asks students to consider the relevant physics. This question is then answered within the chapter.

Concepts & Skills to Review

- net force: vector addition (Section 2.4)
- freebody diagrams (Section 2.4)
- gravitational force (Section 2.5)
- internal and external forces (Section 2.4)

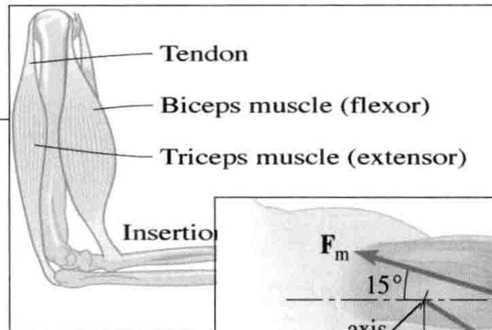
Concepts and Skills to Review

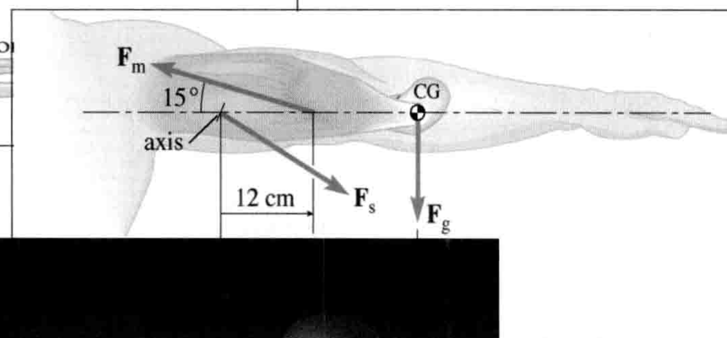
Presented on the first page of each chapter, this unique feature lists important material from previous chapters that students should understand before they start reading.

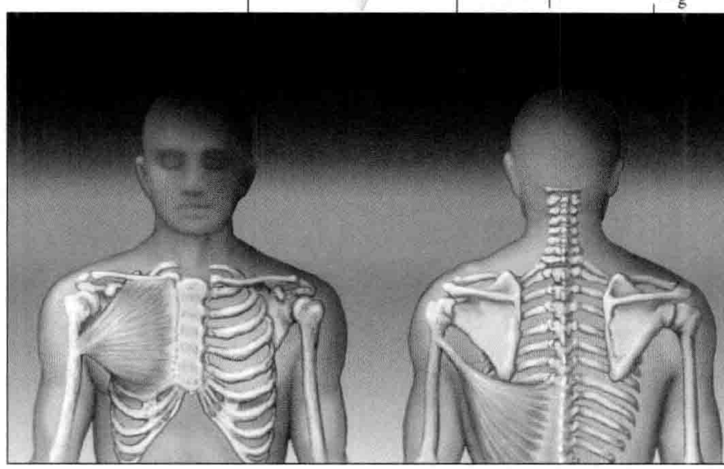
Illustrations and Page Layout to Facilitate and Reinforce Learning

Showcase Illustrations and Diagrammatic Illustrations

Showcase Illustrations and straightforward ***Diagrammatic Illustrations*** are used in combination to help students grasp the concepts. The Showcase Illustrations are designed to be very appealing in order to capture student interest and help them visualize difficult concepts. The Diagrammatic Illustrations are used to further explain and reinforce concepts.







Equations

Important ***equations*** are numbered for ease in reference. Any equations that correspond to important laws are boxed for quick identification.

Reinforcement Notes

Various ***Reinforcement Notes*** appear in the margin to emphasize the important points in the text.

The symbol Δ stands for *the change in*. If the initial value of a quantity Q is Q_0 and the final value is Q_f, then $\Delta Q = Q_f - Q_0$. ΔQ is read "delta Q."

Displacement

$$\Delta \vec{\mathbf{r}} = \vec{\mathbf{r}}_f - \vec{\mathbf{r}}_0 \qquad (3\text{-}1)$$

Rules or Laws

Statements of important physics ***Rules*** or ***Laws*** are highlighted within the text to help identify the most significant topics.

Newton's Laws of Motion (2-2)

1. If no forces act on an object, then its speed and direction of motion do not change. (If the object is at rest, it remains at rest with a speed of zero; if it is moving, it moves in a straight line with constant speed.)
2. A non-zero net force acting on an object causes its state of motion to change. Quantitatively,

$$\mathbf{F}_{net} = m\mathbf{a}$$

where $\mathbf{F}_{net}$ is the net force, m is the mass, and $\mathbf{a}$ is the acceleration (which measures the rate of change of the velocity.)

3. In an interaction between two objects, the forces that each exerts on the other are equal in magnitude and opposite in direction.

Consistent Problem-Solving Approach

Worked Example

A multipart ***Quantitative*** or ***Conceptual Worked Example*** appears when an important new concept or skill is introduced. A step-by-step approach is used for every worked example presented in the text.

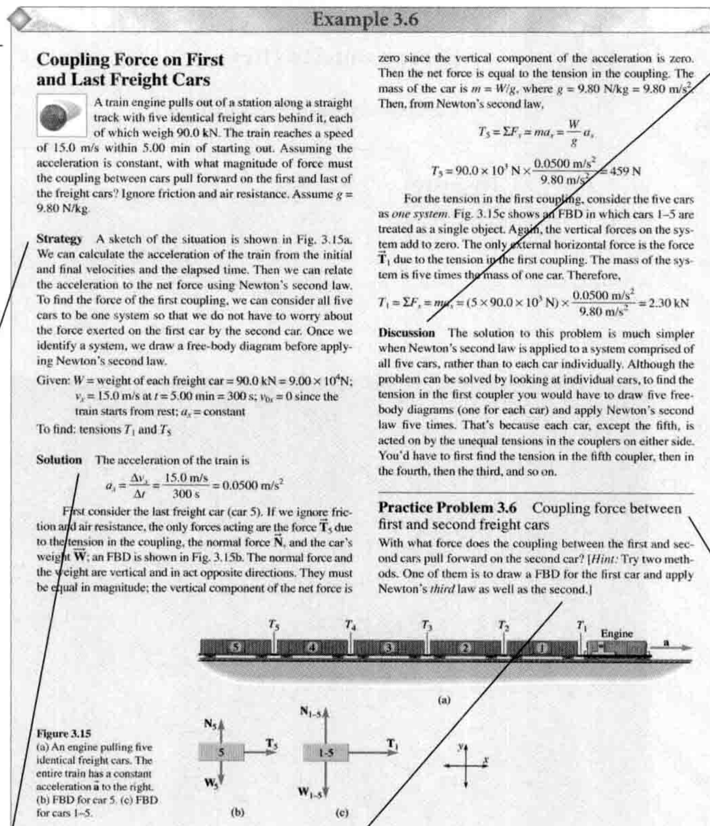
Four-Step Problem-Solving Approach

1. Strategy

Each example begins with a discussion of the strategy to be used in solving the problem. The strategy illustrates the issues that should be considered when attacking a problem: How do we decide what approach to use? What laws of physics apply to the problem? What clues are given in the statement of the question? What assumptions can be made?

2. Solution

The strategy is followed by a numeric ***Solution***. Explanations are intermingled with equations and step-by-step calculations to help the student understand the approach used to solve the problem.



Example 3.6

Coupling Force on First and Last Freight Cars

A train engine pulls out of a station along a straight track with five identical freight cars behind it, each of which weigh 90.0 kN. The train reaches a speed of 15.0 m/s within 5.00 min of starting out. Assuming the acceleration is constant, with what magnitude of force must the coupling between cars pull forward on the first and last of the freight cars? Ignore friction and air resistance. Assume $g =$ 9.80 N/kg.

Strategy A sketch of the situation is shown in Fig. 3.15a. We can calculate the acceleration of the train from the initial and final velocities and the elapsed time. Then we can relate the acceleration to the net force using Newton's second law. To find the force of the first coupling, we can consider all five cars to be one system so that we do not have to worry about the force exerted on the first car by the second car. Once we identify a system, we draw a free-body diagram before applying Newton's second law.

Given: W = weight of each freight car = 90.0 kN = 9.00×10^4 N; $v_x = 15.0$ m/s at $t = 5.00$ min = 300 s; $v_{0x} = 0$ since the train starts from rest; a_x = constant

To find: tensions T_1 and T_5

Solution The acceleration of the train is

$$a_x = \frac{\Delta v_x}{\Delta t} = \frac{15.0\ \text{m/s}}{300\ \text{s}} = 0.0500\ \text{m/s}^2$$

First consider the last freight car (car 5). If we ignore friction and air resistance, the only forces acting are the force $\vec{\mathbf{T}}_5$ due to the tension in the coupling, the normal force $\vec{\mathbf{N}}$, and the car's weight $\vec{\mathbf{W}}$; an FBD is shown in Fig. 3.15b. The normal force and the weight are vertical and in act opposite directions. They must be equal in magnitude; the vertical component of the net force is zero since the vertical component of the acceleration is zero. Then the net force is equal to the tension in the coupling. The mass of the car is $m = W/g$, where $g = 9.80$ N/kg $= 9.80$ m/s². Then, from Newton's second law,

$$T_5 = \Sigma F_x = ma_x = \frac{W}{g} a_x$$

$$T_5 = 90.0 \times 10^3\ \text{N} \times \frac{0.0500\ \text{m/s}^2}{9.80\ \text{m/s}^2} = 459\ \text{N}$$

For the tension in the first coupling, consider the five cars as *one system*. Fig. 3.15c shows an FBD in which cars 1–5 are treated as a single object. Again, the vertical forces on the system add to zero. The only external horizontal force is the force $\vec{\mathbf{T}}_1$ due to the tension in the first coupling. The mass of the system is five times the mass of one car. Therefore,

$$T_1 = \Sigma F_x = ma_x = (5 \times 90.0 \times 10^3\ \text{N}) \times \frac{0.0500\ \text{m/s}^2}{9.80\ \text{m/s}^2} = 2.30\ \text{kN}$$

Discussion The solution to this problem is much simpler when Newton's second law is applied to a system comprised of all five cars, rather than to each car individually. Although the problem can be solved by looking at individual cars, to find the tension in the first coupler you would have to draw five free-body diagrams (one for each car) and apply Newton's second law five times. That's because each car, except the fifth, is acted on by the unequal tensions in the couplers on either side. You'd have to first find the tension in the fifth coupler, then in the fourth, then the third, and so on.

Practice Problem 3.6 Coupling force between first and second freight cars

With what force does the coupling between the first and second cars pull forward on the second car? [*Hint:* Try two methods. One of them is to draw a FBD for the first car and apply Newton's *third* law as well as the second.]

Figure 3.15
(a) An engine pulling five identical freight cars. The entire train has a constant acceleration $\vec{\mathbf{a}}$ to the right. (b) FBD for car 5. (c) FBD for cars 1–5.

3. Discussion

The examples do not end with the solution. Students must also learn how to determine whether an answer is consistent and reasonable by checking order-of-magnitude, verifying the units, and doing an independent calculation when more than one approach is feasible. The ***Discussion*** also draws attention to the problem-solving techniques that were used in the solution.

4. Practice Problems

Every example is immediately followed by a ***Practice Problem***. This allows students to further practice the problem-solving skills illustrated in the example and to reinforce what they have learned. The answer for each practice problem appears at the end of the chapter to allow students to check their work.

Hints

Hints appear within the text to help identify important information and to give clues on what approaches to use or laws to apply. These are plentiful in earlier chapters where students are learning to apply problem-solving techniques.

3.4 NEWTON'S SECOND LAW: FORCE AND ACCELERATION

According to Newton's second law, the acceleration of an object is proportional to the net force on it and is in the same direction. The larger the net force, the larger the acceleration. If the net force is zero, the acceleration is zero and the object moves with constant velocity—possibly zero velocity, but not necessarily. Newton's second law also says that the acceleration is inversely proportional to the object's mass. The same net force acting on two different objects causes a smaller acceleration on the object with greater mass. Mass is a measure of an object's inertia—the amount of resistance to *changes in velocity.*

Mass and weight measure different physical properties. The mass of a body is a measure of its inertia, while weight is a measure of the gravitational force acting on it. Imagine taking a shuffleboard puck to the moon. Since the moon's gravitational field is weaker than the earth's, the puck's weight $\vec{W}$ would be smaller. A smaller normal force $\vec{N}$ would be required to hold it up. On the other hand, the puck's mass, an intrinsic property, is the same. Neglecting the effects of friction, an astronaut playing shuffleboard on the moon would have to exert the same horizontal force on the puck as on earth to give it the same acceleration (Fig. 3.14).

Newton's law relating net force and acceleration is

Newton's Second Law

$$\vec{F}_{net} = m\vec{a} \qquad (3\text{-}8)$$

or

$$\Sigma\vec{F} = m\vec{a}$$

where Σ, the Greek capital letter sigma, stands for *the sum of.* $\Sigma\vec{F}$ means the sum of all the forces acting on a system. The order of the symbols in Eq. (3-8) does not reflect a cause-and-effect relationship; the net force causes the acceleration, not the other way around. The SI unit of force, the newton, is defined in terms of SI base units so that a 1-N net force acting on a 1-kg mass produces an acceleration of 1 m/s^2; therefore

$$1\text{ N} = 1\text{ kg}\cdot\text{m/s}^2$$

When calculating the net force on a system, only *external* forces need be considered. According to Newton's third law, internal forces always add to zero.

Warning Notes

An icon indicates a ***Warning Note*** that describes possible points of confusion or any common misconceptions that may apply to a particular concept.

Problem-Solving Tip

An icon points out ***Problem-Solving Tips*** that guide students in applying problem-solving techniques.

Problem-Solving Strategies for Newton's Second Law

- Decide what objects will have Newton's second law applied to them.
- Identify all the interactions affecting that object.
- Draw a free-body diagram to show all the forces acting on the object.
- Find the net force by adding the forces as vectors.
- Use Newton's second law to relate the net force to the acceleration.

Problem-Solving Strategies

Problem-Solving Strategies give detailed information on solving a particular type of problem. These are supplied for the most fundamental physics rules and laws.

Applying Physics to the Real World

Physics at Home

Go to a balcony or climb up a ladder and drop a basket-style paper coffee filter (or a cupcake paper) and a penny simultaneously. Air resistance on the penny is negligible unless it is dropped from a very high balcony. At the other extreme, the effect of air resistance on the coffee filter is very noticeable; it reaches its terminal speed almost immediately. Stack several (two to four) coffee filters together and drop them simultaneously with a single coffee filter. Why is the terminal speed higher for the stack? Crumple a coffee filter into a ball and drop it simultaneously with the penny. Air resistance on the coffee filter is now reduced, but still noticeable.

Physics at Home

Throughout the chapters of this text students will find ***Physics at Home*** activities. These are designed to be performed individually at home to help students further understand and visualize certain physics concepts.

Making The Connection: motion of a train

problem. The engineer wants to call the railroad office he tell them where to find the train? He might say som of the old trestle bridge." Notice that he uses a point o Then he states how far the train is from that point and i of the three pieces (the reference point, the distance, ar tion of the train's whereabouts is ambiguous.

The same thing is done in physics. First, we cho **origin.** Then, to describe the location of something, w

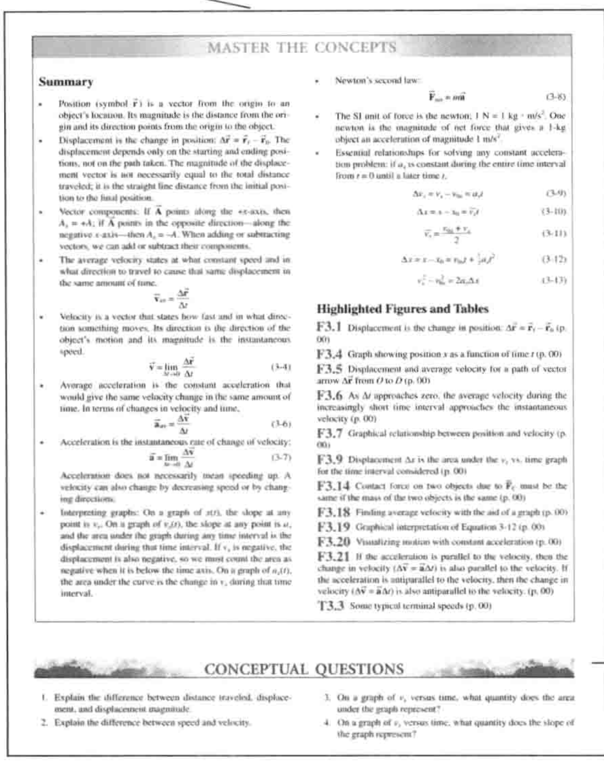
Making The Connection

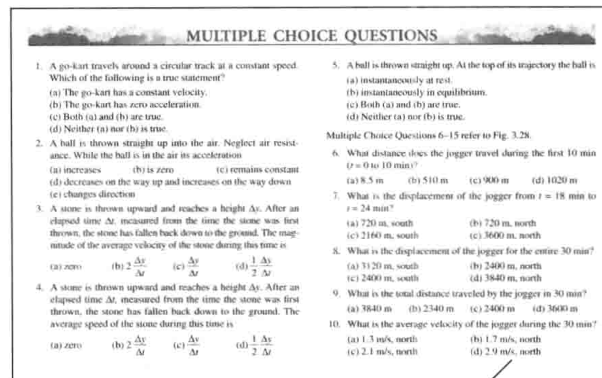
The ***Making The Connection*** icon indicates areas in the text where physics can be applied to other areas in your students' lives. Familiar topics and interests are discussed in the text and examples, drawing from biology, archaeology, astronomy, sports, and the everyday world.

End-of-Chapter Material

Master the Concepts

The ***Master the Concepts*** section gives students a quick review of the chapter. A ***Summary*** lists important concepts and equations, while the ***Highlighted Figures and Tables*** section identifies important ideas that are graphically represented within the chapter.





Multiple Choice Questions

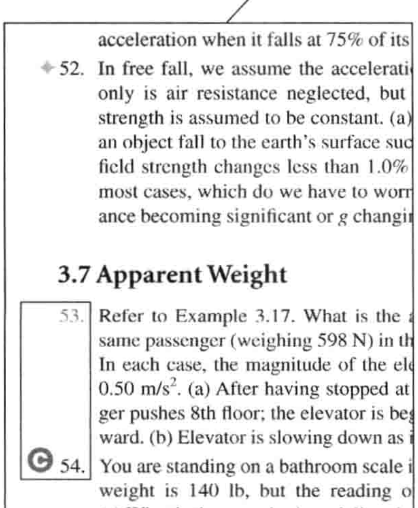
The ***Multiple Choice Questions*** allow students to do a quick self-test and also provide practice for the type of questions found on the MCAT exam. Answers can be found at the end of the book.

Conceptual Questions

The ***Conceptual Questions*** are designed to test students' qualitative understanding of the key ideas within the chapter.

Problems

A large variety of ***Problems*** are given by chapter section to check the student's quantitative understanding of the chapter. ***Comprehensive Problems*** also allow students to test their overall understanding of the chapter.



Paired by Concept

Some problems are paired by concept, and their numbers are connected by a ruled box. Only one problem of the pair has an answer available at the end of the book and a solution available in the Student Solutions Manual.

Color Coded

Blue problem numbers indicate those with solutions available in the College Physics Student Solutions Manual.

Difficulty Level

Difficulty level is designated by ✦ for problems of intermediate difficulty and ✦✦ for more demanding problems.

Conceptual and Quantitative

A Ⓒ indicates a problem that combines conceptual and quantitative problem solving.