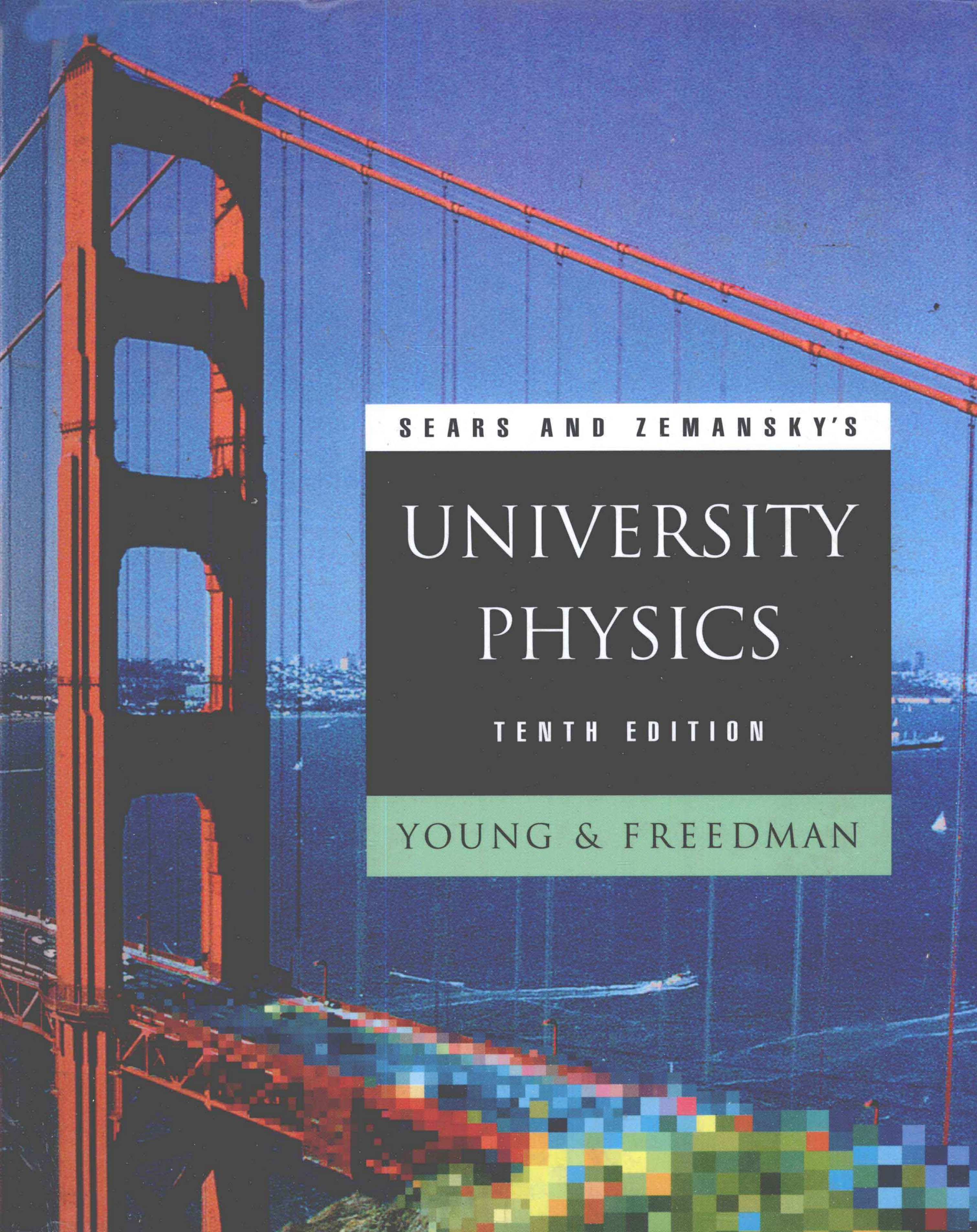

SEARS AND ZEMANSKY'S

UNIVERSITY PHYSICS

TENTH EDITION

YOUNG & FREEDMAN

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UNIVERSITY PHYSICS

TENTH EDITION

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PREFACE

This book is the product of a half century of innovation in physics education. When the first edition of *University Physics* by Francis W. Sears and Mark W. Zemansky appeared in 1949, it was revolutionary in its emphasis on the fundamental principles of physics and how to apply them. This Commemorative Tenth Edition continues to emphasize principles and applications as it provides today's students with a broad, rigorous, yet accessible introduction to calculus-based physics. The success of *University Physics* with generations of students and educators in all parts of the world is a testament to the merits of this approach.

Two key objectives guided the writing of this text: helping students develop physical intuition, and helping them build strong problem-solving skills. Also reflected throughout are the results of two decades of research in physics education on the conceptual pitfalls that commonly plague beginning physics students. These pitfalls include the notions that force is required for motion, that electric current is "used up" as it goes around a circuit, and that the product of a body's mass and its acceleration is itself a force. A key focus of this edition is to discuss not only the correct way to analyze a situation or solve a problem, but also the reason why the wrong way (which may have occurred to the student first) is indeed wrong.

The prose style of the book continues to be relaxed and conversational, without being colloquial or excessively familiar. We see the student as our partner in learning, not as an audience to be lectured to from atop a platform. This style makes it much easier for us to convey to the student our own excitement and enthusiasm for the beauty, intellectual challenge, and fundamental unity of physics.

In preparing the Tenth Edition, we have relied heavily on the comments of a great many faculty and students on how best to help them meet the challenges of physics education. Based on these comments, we have designed the following features of this edition.

A GUIDE FOR THE STUDENT

Many physics students experience difficulty simply because they don't know how to make the best use of their textbook. A section entitled "How to Succeed in Physics by Really Trying," which follows this preface, serves as a "user's manual" to all the features of this book. This section, written by Professor Mark Hollabaugh (Normandale Community College), also gives a number of helpful study hints. We strongly encourage *every* student to read this section!

CHAPTER ORGANIZATION

The *Introduction* to each chapter gives specific examples of the chapter's content and connects it with what has come before. At the end of each chapter is a *Summary* of the most important principles introduced in the chapter, along with the associated *Key Equations.* The summary also includes a list of *Key Terms* that the student should have learned to use, with references to the page on which each term is first introduced.

CONTENTS

Some of the most significant content features of this edition include:

- In Chapter 2, motion diagrams help students to distinguish between position, velocity, and acceleration in one-dimensional motion (see pp. 40–41).
- Chapter 12 has been updated with new data on the supermassive black hole at the center of our Milky Way galaxy.
- We discuss the microscopic interpretation of entropy in Chapter 18.
- A qualitative introduction to the ideas behind Gauss's law is given in Chapter 23.
- Chapter 28 on magnetic fields and forces explains the attraction and repulsion of magnets and magnetic materials.
- The discussion of electromagnetic induction in Chapter 30 and of inductance in Chapter 31 has been rewritten to make these essential but challenging concepts more accessible to students.
- Every chapter now includes a selection of photographs that illustrate how physical principles manifest themselves in the natural world and in our technological society.

QUESTIONS AND PROBLEMS

At the end of each chapter is a collection of *Discussion Questions,* intended to probe and extend the student's conceptual understanding, followed by an extensive set of problems. The problems have been revised and their number increased, including many new problems drawn from astrophysics, biology, and aerodynamics. Many problems have a conceptual part in which students must discuss and explain their results. The problems are grouped into *Exercises,* which are single-concept problems keyed to specific sections of the text; *Problems,* usually requiring two or more nontrivial steps; and *Challenge Problems,* intended to challenge the strongest students. Many new questions, exercises, and problems, especially for Chapters 38, 41, 42, 43, 44, and 45, were suggested by Professor A. Lewis Ford (Texas A&M University) and Professor Tom Sandin (North Carolina A&T State University).

PROBLEM-SOLVING STRATEGIES

Problem-Solving Strategy sections, an extremely popular feature of the book, have been retained and strengthened. They have proved to be a very substantial help, especially to the many earnest but bewildered students who "understood the material but couldn't do the problems." (See, for example, pp. 110, 121, and 171.)

EXAMPLES

Each *Problem-Solving Strategy* section is followed immediately by one or more worked-out examples that illustrate the strategy. Several of these are purely qualitative, such as Examples 6–6 (Comparing kinetic energies, p. 173), 8–1 (Momentum vs. kinetic energy, p. 230), and 18–7 (Isentropic processes, p. 576). Many examples are drawn from real-life situations relevant to the student's own experience. Units and correct significant figures in examples are always carried through all stages of numerical calculations.

Example solutions always begin with a statement of the general principles to be used and, when necessary, a discussion of the reason for choosing them. We emphasize modeling in physics, showing the student how to begin with a seemingly complex situation, make simplifying assumptions, apply the appropriate physical principles, and evaluate the final result. Does it make sense? Is it what you expected? How can you check it?

"CAUTION" PARAGRAPHS

In the text of each chapter we have labeled certain paragraphs with the word **CAUTION.** These paragraphs alert the student to common misconceptions or to points of potential confusion. (See, for example, pp. 102, 140, and 167.) We think of them as being similar to the flagged paragraphs in the user's manual for a power drill or a VCR, describing potential sources of trouble when using the equipment.

ACTIVPHYSICS LINKS

An important and unique supplement to *University Physics* is the set of *ActivPhysics I* and *ActivPhysics 2* CD-ROMs and workbooks, developed by Professors Alan Van Heuvelen and Paul D'Alessandris and published by Addison Wesley Longman. By combining carefully designed interactive simulations with proven pedagogy, *ActivPhysics* helps students become adept at solving problems about dynamic physical phenomena. Icons throughout the text of *University Physics* indicate which of the 200-plus exercises in *ActivPhysics* correspond to specific topics in this book. Exercises 1.1 through 10.10 appear in *ActivPhysics I,* while Exercises 11.1 through 20.4 are in *ActivPhysics 2.* For more information about the *ActivPhysics* CD-ROMs (compatible with both Macintosh and Windows) and workbooks, see below under "Supplements."

CASE STUDIES

We have included 10 optional sections called *Case Studies,* each building on the material of its chapter. Some (Neutrinos, Black Holes, Photons) emphasize connections between classical and modern physics. Others (Automotive Power, Energy Resources, Power Distribution Systems) have an engineering flavor; still others (Baseball Trajectories, Electric Potential Maps) emphasize computer simulations and include computer exercises for the student. All case studies have corresponding end-of-chapter problems.

NOTATION AND UNITS

Students often have a hard time keeping track of which quantities are vectors and which are not. In this edition, we use boldface italic symbols with an arrow on top for vector quantities, such as $\vec{\boldsymbol{v}}$, $\vec{\boldsymbol{a}}$, and $\vec{\boldsymbol{F}}$; unit vectors have a caret on top, such as $\hat{\boldsymbol{\imath}}$. Boldface **+**, **–**, **×**, and **=** signs are used in vector equations to emphasize the distinction between these operations and operations with ordinary numbers.

In this edition SI units are used exclusively. English unit conversions are included where appropriate. The joule is used as the standard unit of energy of all forms, including heat.

FLEXIBILITY

The book is adaptable to a wide variety of course outlines. There is plenty of material for an intensive three-semester or five-quarter course. Most instructors will find that there is too much material for a one-year course, but it is easy to tailor the book to a variety of one-year course plans by omitting certain chapters or sections. For example, any or all of the chapters on relativity, fluid mechanics, acoustics, electromagnetic waves, optical instruments, and several other topics can be omitted without loss of continuity. Some sections that are unusually challenging or somewhat out of the mainstream have been identified with an asterisk preceding the section title; these, too, may be omitted. In any case, no one should feel constrained to work straight through the entire book. We encourage instructors to select the chapters that fit their needs, omitting material that is not appropriate for the objectives of a particular course.

STANDARD, EXTENDED, AND SPLIT VERSIONS

This edition is available in three versions. The Standard version (ISBN 0–201–60322–5) includes 39 chapters, ending with the special theory of relativity. The Extended version (ISBN 0–201–60336–5) adds seven chapters on modern physics, including the physics of atoms, molecules, condensed matter, nuclei, and elementary particles. The Split version includes all 46 chapters in three softbound volumes: Volume 1, Chapters 1–21 (ISBN 0–201–60329–2); Volume 2, Chapters 22–39 (ISBN 0–201–60335–7); and Volume 3, Chapters 40–46 (ISBN 0–201–65663–9).

SUPPLEMENTS

For the Student: The *Online Course Companion Web site* (http://www.awlonline.com/young) offers problem solving tips, interactive quizzes, key concepts for each chapter of *University Physics,* a glossary, tips for success in physics, web links to applications of physical concepts, and much more.

The *ActivPhysics* CD-ROMs and workbooks, developed by Professors Alan Van Heuvelen and Paul D'Alessandris, use interactive simulations and multiple representations to help students become better physics problem-solvers. The CD-ROMs are compatible with both Macintosh and Windows. *ActivPhysics 1* (ISBN 0–201–69482–4) covers the topics of Chapters 1–21, and *ActivPhysics 2* (ISBN 0–201–36111–6) covers the material found in Chapters 22–46. As mentioned above, icons in the text of *University Physics* show the connections between topics in the book and exercises in *ActivPhysics.*

The *Study Guide,* prepared by Professors James R. Gaines and William F. Palmer, reinforces the text's emphasis on problem-solving strategies and student misconceptions. The *Study Guide for Volume 1* (ISBN 0–201–61835–4) covers Chapters 1–21, and the *Study Guide for Volumes 2 and 3* (ISBN 0–201–61834–6) covers Chapters 22–46.

The *Student Solutions Manual,* prepared by Professor A. Lewis Ford, includes completely worked-out solutions for about two-thirds of the odd-numbered problems in *University Physics.* (Answers to all odd-numbered problems are found in this book following the Appendices.) The *Student Solutions Manual for Volume 1* (ISBN 0–201–64394–4) covers Chapters 1–21, and the *Student Solutions Manual for Volumes 2 and 3* (ISBN 0–201–64395–2) covers Chapters 22–46.

For the Instructor: The *Instructor's Solutions Manual,* prepared by Professor Mark Hollabaugh and Dr. Thomas D. Gutierrez, contains worked-out solutions to all exercises, problems, and challenge problems. The *Instructor's Solutions Manual for Volume 1* covers Chapters 1–21 (ISBN 0–201–61836–2) and the *Instructor's Solution Manual for Volumes 2 and 3* covers Chapters 22–46 (ISBN 0–201–61837–0). It is also available as a cross-platform CD-ROM (ISBN 0–201–65679–5). With the CD-ROM, you can read, edit, and print any solutions you choose, as well as post them on your secure, password-protected class web site.

The *Instructor's Guide for an Active Learning Classroom* (ISBN 0–201–65676–0) offers quick strategies for tailoring your course to include active learning techniques. This supplement is ideal for instructors who want to integrate these techniques into their course, but do not have time to create a new teaching plan.

The *Online Course Companion Web site* (http://www.awlonline.com/young) makes it easy to put your course syllabus and assignments on the web and password-protect your course information. Through the site, students can submit assignments to you or your teaching assistants.

The *Instructor's Presentation CD-ROM* contains the full-color line art figures from the text. Images may be exported into other programs, such as PowerPoint.

The *Overhead Transparencies* (ISBN 0–201–61833–8) include 200 four-color figures from the text. These are on acetate for use on an overhead projector.

The *Test Item File* (ISBN 0–201–60344–6), written by Dr. Elliot Farber and Professor Michael Browne, includes multiple-choice and short-answer problems. The accompanying TestGen software (ISBN 0–201–65662–0), compatible with both Macintosh and Windows, makes it easy to edit these test items, assemble them into an exam, and generate an answer key.

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PLEASE TELL US WHAT YOU THINK!

We welcome communications from students and professors, especially concerning errors or deficiencies that you find in this edition. We have devoted a lot of time and effort to writing the best book we know how to write, and we hope it will help you to teach and learn physics. In turn, you can help us by letting us know what still needs to be improved! Please feel free to contact us either by ordinary mail or electronically. Your comments will be greatly appreciated.

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How to Succeed in Physics by Really Trying

Mark Hollabaugh, Normandale Community College

Physics encompasses the large and the small, the old and the new. From the atom to galaxies, from electrical circuitry to aerodynamics, physics is very much a part of the world around us. You probably are taking this introductory course in calculus-based physics because it is required for subsequent courses you plan to take in preparation for a career in science or engineering. Your professor wants you to learn physics and to enjoy the experience. He or she is very interested in helping you learn this fascinating subject. That is part of the reason your professor chose this textbook for your course. That is also the reason why Drs. Young and Freedman asked me to write this introductory section. We want you to succeed!

The purpose of this section of *University Physics* is to give you some ideas that will assist your learning. Specific suggestions on how to use the textbook will follow a brief discussion of general study habits and strategies.

PREPARATION FOR THIS COURSE

If you had high school physics, you will probably learn concepts faster than those who have not because you will be familiar with the language of physics. If English is a second language for you, keep a glossary of new terms that you encounter and make sure you understand how they are used in physics. Likewise, if you are farther along in your mathematics courses, you will pick up the mathematical aspects of physics faster. Even if your mathematics is adequate, you may find a book such as Arnold D. Pickar's *Preparing for General Physics: Math Skill Drills and Other Useful Help (Calculus Version)* to be useful. Your professor may actually assign sections of this math review to assist your learning.

LEARNING TO LEARN

Each of us has a different learning style and a preferred means of learning. Understanding your own learning style will help you to focus on aspects of physics that may give you difficulty and to use those components of your course that will help you overcome the difficulty. Obviously you will want to spend more time on those aspects that give you the most trouble. If you learn by hearing, lectures will be very important. If you learn by explaining, then working with other students will be useful to you. If solving problems is difficult for you, spend more time learning how to solve problems. Also, it is important to understand and develop good study habits. Perhaps the most important thing you can do for yourself is to set aside adequate, regularly scheduled, study time in a distraction-free environment.

Answer the following questions for yourself:

- Am I able to use fundamental mathematical concepts from algebra, geometry and trigonometry? (If not, plan a program of review with help from your professor.)
- In similar courses, what activity has given me the most trouble? (Spend more time on this.) What has been the easiest for me? (Do this first; it will help to build your confidence.)
- Do I understand the material better if I read the book before or after the lecture? (You may learn best by skimming the material, going to lecture, and then undertaking an in-depth reading.)
- Do I spend adequate time in studying physics? (A rule of thumb for a class like this is to devote, on the average, 2.5 hours out of class for each hour in class. For a course

meeting 5 hours each week, that means you should spend about 10 to 15 hours per week studying physics.)

- Do I study physics every day? (Spread that 10 to 15 hours out over an entire week!) At what time of the day am I at my best for studying physics? (Pick a specific time of the day and stick to it.)
- Do I work in a quiet place where I can maintain my focus? (Distractions will break your routine and cause you to miss important points.)

WORKING WITH OTHERS

Scientists or engineers seldom work in isolation from one another but rather work cooperatively. You will learn more physics and have more fun doing it if you work with other students. Some professors may formalize the use of cooperative learning or facilitate the formation of study groups. You may wish to form your own informal study group with members of your class who live in your neighborhood or dorm. If you have access to e-mail, use it to keep in touch with one another. Your study group is an excellent resource when reviewing for exams.

LECTURES AND TAKING NOTES

An important component of any college course is the lecture. In physics this is especially important because your professor will frequently do demonstrations of physical principles, run computer simulations, or show video clips. All of these are learning activities that will help you to understand the basic principles of physics. Don't miss lectures, and if for some reason you do, ask a friend or member of your study group to provide you with notes and let you know what happened.

Take your class notes in outline form, and fill in the details later. It can be very difficult to take word for word notes, so just write down key ideas. Your professor may use a diagram from the textbook. Leave a space in your notes and just add the diagram later. After class, edit your notes, filling in any gaps or omissions and noting things you need to study further. Make references to the textbook by page, equation number, or section number.

Make sure you ask questions in class, or see your professor during office hours. Remember the only "dumb" question is the one that is not asked. Your college may also have teaching assistants or peer tutors who are available to help you with difficulties you may have.

EXAMINATIONS

Taking an examination is stressful. But if you feel adequately prepared and are well-rested, your stress will be lessened. Preparing for an exam is a continual process; it begins the moment the last exam is over. You should immediately go over the exam and understand any mistakes you made. If you worked a problem and made substantial errors, try this: Take a piece of paper and divide it down the middle with a line from top to bottom. In one column, write the proper solution to the problem. In the other column, write what you did and why, if you know, and why your solution was incorrect. If you are uncertain why you made your mistake, and how to avoid it again, talk with your professor. Physics continually builds on fundamental ideas and it is important to correct any misunderstandings immediately. Warning: While cramming at the last minute may get you through the *present* exam, you will not adequately retain the concepts for use on the *next* exam.

USING YOUR TEXTBOOK

Now let's take a look at specific features of *University Physics* that will help you understand the concepts of physics. At its heart, physics is not equations and numbers. Physics is a way of looking at the universe and understanding how the universe works and how its various parts relate to each other. And although solving quantitative problems is an important part of physics, it is equally important for you to understand concepts qualitatively. Your textbook will help you in both areas.

First of all, don't be afraid to write in your book. It is more important for you to learn the concepts of physics than to keep your book in pristine condition. Write in the margins, make cross references. Take notes in your notebook as you read. *University Physics* is your primary "reference book" for this course. Refer to it often to help you understand the concepts you hear in lecture. Become familiar with the contents of the appendices and end papers.

CAUTION ▶ Please note that the quantity $m\vec{a}$ is *not* a force. All that Eqs. (4–7) and (4–8) say is that the vector $m\vec{a}$ is equal in magnitude and direction to the vector sum $\Sigma\vec{F}$ of all the forces acting on the body. It's incorrect to think of acceleration as a force; rather, acceleration is a result of a nonzero net force. It's "common sense" to think that there is a "force of acceleration" that pushes you back into your seat when your car accelerates forward from rest. But *there is no such force;* instead, your inertia causes you to tend to stay at rest relative to the earth, and the car accelerates around you. The "common sense" confusion arises from trying to apply Newton's second law in a frame of reference where it isn't valid, like the non-inertial reference frame of an accelerating car. We will always examine motion relative to *inertial* frames of reference only. ◀

In learning how to use Newton's second law, we will begin in this chapter with examples of straight-line motion. Then in Chapter 5 we will consider more general cases and develop more detailed problem-solving strategies for applying Newton's laws of motion.

CAUTION!

Educational research has found numerous misconceptions or misunderstandings that students frequently have when they study physics. Dr. Freedman has added *Caution!* paragraphs to warn you about these potential pitfalls. Heed them!

WORKED EXAMPLES

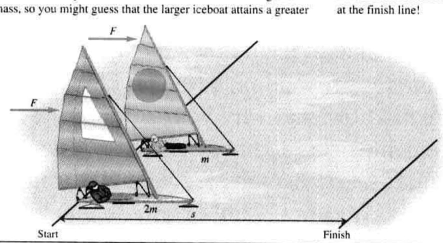
Your professor will work example problems in class to illustrate the application of the concepts of physics to real-world problems. You should work through all the examples in the textbook, filling in any missing steps, and making note of things you don't understand. Get help with the concepts that confuse you!

EXAMPLE 6–6

Comparing kinetic energies Two iceboats like the one in Example 5–5 (Section 5–3) hold a race on a frictionless horizontal lake (Fig. 6–9). The two iceboats have masses m and $2m$, respectively. Each iceboat has an identical sail, so the wind exerts the same constant force $\vec{F}$ on each iceboat. The two iceboats start from rest and cross the finish line a distance s away. Which iceboat crosses the finish line with greater kinetic energy?

SOLUTION If you simply use the mathematical definition of kinetic energy, $K = \frac{1}{2}mv^2$ (Eq. (6–5)), the answer to this problem isn't immediately obvious. The iceboat of mass $2m$ has greater mass, so you might guess that the larger iceboat attains a greater kinetic energy at the finish line. But the smaller iceboat, of mass m, will cross the finish line with a greater speed, and you might guess that *this* iceboat will have the greater kinetic energy. How can we decide?

The correct way to approach this problem is to remember that *the kinetic energy of a particle is just equal to the total work done to accelerate it from rest.* Both iceboats travel the same distance s, and only the horizontal force F in the direction of motion does work on either iceboat. Hence the total work done between the starting line and the finish line is the *same* for each iceboat, $W_{tot} = Fs$. At the finish line, each iceboat has a kinetic energy equal to the work W_{tot} done on it, because each iceboat started from rest. So both iceboats have the *same* kinetic energy at the finish line!



6–9 A race between iceboats.

Problem–Solving Strategy

PROBLEMS USING MECHANICAL ENERGY

1. First decide whether the problem should be solved by energy methods, by using $\Sigma \vec{F} = m\vec{a}$ directly, or by a combination. The energy approach is particularly useful when the problem involves motion with varying forces, motion along a curved path (discussed later in this section), or both. But if the problem involves elapsed time, the energy approach is usually *not* the best choice because this approach doesn't involve time directly.
2. When using the energy approach, first decide what the initial and final states (the positions and velocities) of the system are. Use the subscript 1 for the initial state and the subscript 2 for the final state. It helps to draw sketches showing the initial and final states.
3. Define your coordinate system, particularly the level at which $y = 0$. You will use this to compute gravitational potential energies. Equation (7–2) assumes that the positive direction for y is upward; we suggest that you use this choice consistently.
4. List the initial and final kinetic and potential energies, that is, K_1, K_2, U_1, and U_2. In general, some of these will be known and some will be unknown. Use algebraic symbols for any unknown coordinates or velocities.
5. Identify all nongravitational forces that do work. A free-body diagram is always helpful. Calculate the work W_{other} done by all these forces. If some of the quantities you need are unknown, represent them by algebraic symbols.
6. Relate the kinetic and potential energies and the nongravitational work W_{other} using Eq. (7–7). If there is no nongravitational work, this becomes Eq. (7–4). It's helpful to draw bar graphs showing the initial and final values of K, U, and $E = K + U$. Then solve to find whatever unknown quantity is required.
7. Keep in mind, here and in later sections, that the work done by each force must be represented either in $U_1 - U_2 = -\Delta U$ or as W_{other}, but *never* in both places. The gravitational work is included in ΔU, so do not include it again in W_{other}.

PROBLEM-SOLVING STRATEGIES

One of the features of *University Physics* that first caught my eye as a teacher were the *Problem-Solving Strategy* boxes. This is the advice I would give to a student who came to me for help with a physics problem. Physics teachers approach a problem in a very systematic and logical manner. These boxes will help you as a beginning problem solver to do the same. Study these suggestions in great detail and implement them. In many cases these strategy boxes will tell you *how* to visualize an abstract concept.

CASE STUDIES

Physics relates to the real world, and these *Case Studies* will give you examples of applying physics to real science or engineering problems.

6–6 AUTOMOTIVE POWER

A Case Study in Energy Relations

The power requirements of a gasoline-powered automobile are an important and practical example of the concepts in this chapter. If roads were frictionless and air resistance didn't exist, there would be no need for an automobile to have an engine. All you'd need to go for a drive would be a few strong friends to give you a push to get started and a few other friends at your destination to stop you. (Steering on frictionless roads would be a problem, though.) In the real world, however, a moving car without an engine slows down because of forces that resist its motion. The engine's function is to continuously provide power to overcome this resistance. So to understand how much power is required from a car's engine, we must analyze the forces that act on the car.

Two forces oppose the motion of an automobile: rolling friction and air resistance. We described rolling friction in Section 5–4 in terms of a coefficient of rolling friction μ_r. A typical value of μ_r for properly inflated tires on hard pavement is 0.015. A Porsche 911 Carrera has a mass of 1251 kg and a weight of $(1251\ \text{kg})(9.80\ \text{m/s}^2) = 12{,}260$ N, and

SUMMARY, REVIEW QUESTIONS AND PROBLEMS

The most important concepts are listed in the *Key Terms*. Keep a glossary of terms in your notebook. Your professor may indicate through the use of course objectives which terms are important for you to know. The *Summary* will give you a quick review of the chapter's main ideas and the equations that represent those ideas mathematically. Everything else can be derived from these general equations. If your professor assigns *Problems* at the end of the chapter, make sure you work them carefully with other students. If solutions are available, do not look at the answer until you have struggled with the problem and compared your answer with someone else's. If the two of you agree on the answer, then look at the solution. If you have made a mistake, go back and rework the problem. Do not simply read the problem. You will note that the *Exercises* are keyed to specific sections of the chapter and are easier. Work on these before you attempt the *Problems* or *Challenge Problems* which typically use multiple concepts.

Well, there you have it. We hope these suggestions will benefit your study of physics. Strive for understanding and excellence, and be persistent in your learning.

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