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pull back? One way to find out is to attach the spring to a bar, as shown in Figure 10.14. If you now stretch the spring to length or unstretched, length. A force that restores a system to an equilibrium position is called a restoring force. Similarly, a compressed spring tries to re-expand to its equilibrium. That is, the data fall along the straight line $F = -kx$. The graph shows that the restoring force is proportional to the displacement $F$. The slope of the force-versus-displacement graph, is $k$. The restoring force is proportional to the displacement that the end of the spring has moved, which we call the restoring force $(k)$.

Before: After:

**EXAMPLE 4.15 Analyzing rotational data**

We know the velocities before and after the collision, so we can use the conservation of linear momentum to find the angular acceleration.

$$v_{coll} = \frac{1.89 \text{ rad/s}}{0.15 \text{ m}} = 12.6 \text{ rad/s}^2$$

We can then use its slope to determine the angular acceleration:

$$\alpha = \frac{v_{coll}^2 - v_{in}^2}{r} = \frac{(12.6 \text{ rad/s})^2 - (2.5 \text{ rad/s})^2}{0.38 \text{ m}} = 0.38 \text{ rad/s}^2$$

**TACTIC 4.20 Drawing a before-and-after pictorial representation**

At the heart of the problem-solving instruction is the consistent 4-step **MODEL/ VISUALIZE/ SOLVE/ ASSESS** approach, used throughout the book and all supplements. **Problem-Solving Strategies** provide detailed guidance for particular topics and categories of problems, often drawing on key skills outlined in the step-by-step procedures of Tactic Boxes. Problem-Solving Strategies and Tactic Boxes are also illustrated in dedicated MasteringPhysics® **Skill-Builder Tutorials**.

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Promotes deeper understanding…
... using powerful techniques from multimedia learning theory that focus and structure student learning, and improve engagement and retention.

14 Oscillations

NEW! Illustrated Chapter Previews give an overview of the upcoming ideas for each chapter, setting them in context, explaining their utility, and tying them to existing knowledge (through Looking Back references).

Summary

- General Principles
  - Hooke's Law
  - Damping and Resonance

- Important Concepts
  - Phase
  - Energy of oscillations

- Applications
  - Simple harmonic motion
  - Pendulums

- Terms and Notation

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NEW! Video Tutor Demonstrations feature “pause-and-predict” demonstrations of key physics concepts and incorporate assessment as the student progresses to actively engage them in understanding the key conceptual ideas underlying the physics principles.
51. A geologist needs to determine the local value of \( g \). Unfortunately, he only tools are a meter stick, a saw, and a stopwatch. He starts by hanging the meter stick from one end and measuring its frequency as it swings. He then swings off 20 cm—using the centimeter markings—and measures the frequency again. After two more cuts, these are his data:

<table>
<thead>
<tr>
<th>Length (cm)</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.62</td>
</tr>
<tr>
<td>30</td>
<td>0.57</td>
</tr>
<tr>
<td>60</td>
<td>0.79</td>
</tr>
<tr>
<td>90</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Use the best-fit line of an appropriate graph to determine the local value of \( g \).

An increased emphasis on symbolic answers encourages students to work algebraically.

**NEW! Data-based end-of-chapter problems** allow students to practice drawing conclusions from data (as demonstrated in the new data-based examples in the text).

**NEW! BIO problems** are set in life-science, bioengineering, or biomedical contexts.

**NEW! Student Workbook exercises** help students work through a full solution symbolically, structured around the relevant textbook Problem-Solving Strategy.

**NEW! Enhanced end-of-chapter problems** in MasteringPhysics now offer additional support such as problem-solving strategy hints, relevant math review and practice, links to the eText, and links to the related Video Tutor Solution.

**NEW! Math Remediation** found within selected MasteringPhysics tutorials provide just-in-time math help and allow students to brush up on the most important mathematical concepts needed to successfully complete assignments. This new feature links students directly to math review and practice helping students make the connection between math and physics.
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NEW! Learning Outcomes. In addition to being able to create your own learning outcomes to associate with questions in an assignment, you can now select content that is tagged to a large number of publisher-provided learning outcomes. You can also print or export student results based on learning outcomes for your own use or to incorporate into reports for your administration.
Preface to the Teacher

In 2003 we published *Physics for Scientists and Engineers: A Strategic Approach*. This was the first comprehensive calculus-based introductory textbook built from the ground up on research into how students can more effectively learn physics. The development and testing that led to this book had been partially funded by the National Science Foundation. For the second edition, and now the third, we have built on the research-proven instructional techniques introduced in the first edition and the extensive feedback from thousands of users to take student learning even further.

Objectives

My primary goals in writing *Physics for Scientists and Engineers: A Strategic Approach* have been:

- To produce a textbook that is more focused and coherent, less encyclopedic.
- To move key results from physics education research into the classroom in a way that allows teachers to use a range of teaching styles.
- To provide a balance of quantitative reasoning and conceptual understanding, with special attention to concepts known to cause student difficulties.
- To develop students’ problem-solving skills in a systematic manner.
- To support an active-learning environment.

What’s New to This Edition

For this third edition, we continue to apply the best results from educational research, and to refine and tailor them for this course and its students. At the same time, the extensive feedback we’ve received has led to many changes and improvements to the text, the figures, and the end-of-chapter problems. These include:

- New illustrated Chapter Previews give a visual overview of the upcoming ideas, set them in context, explain their utility, and tie them to existing knowledge (through Looking Back references). These Previews build on the cognitive psychology concept of an “advance organizer.”
- New Challenge Examples illustrate how to integrate multiple concepts and use more sophisticated reasoning in problem solving, ensuring an optimal range of worked examples for students to study in preparation for homework problems.
- New Data-based Examples help students with the skill of drawing conclusions from laboratory data. Designed to supplement lab-based instruction, these examples also help students in general with mathematical reasoning, graphical interpretation, and assessment of results.

End-of-chapter problem enhancements include the following:

- Data from MasteringPhysics have been thoroughly analyzed to ensure an optimal range of difficulty, problem types, and topic coverage. In addition, the wording of every problem has been reviewed for clarity. Roughly 20% of the end-of-chapter problems are new or significantly revised.
- Data-based problems allow students to practice drawing conclusions from data (as demonstrated in the new data-based examples in the text).
An increased emphasis on symbolic answers encourages students to work algebraically. The Student Workbook also contains new exercises to help students work through symbolic solutions.

Bio problems are set in life-science, bioengineering, or biomedical contexts.

Targeted content changes have been carefully implemented throughout the book. These include:

- Life-science and bioengineering worked examples and applications focus on the physics of life-science situations.
- Descriptive text throughout has been streamlined to focus the presentation and generate a shorter text.
- The chapter on Modern Optics and Matter Waves has been re-worked into Chapters 38 and 39 to streamline the coverage of this material.

At the front of the book, you’ll find an illustrated walkthrough of the new pedagogical features in this third edition. The Preface to the Student demonstrates how all the book’s features are designed to help your students.

Textbook Organization

There’s a growing sentiment that quantum physics is quickly becoming the province of engineers, not just scientists, and that even a year-long course should include a reasonable introduction to quantum ideas. The Instructor Guide outlines a couple of routes through the book that allow most of the quantum physics chapters to be included in a year-long course. I’ve written the book with the hope that an increasing number of teachers will choose one of these routes.

The full textbook is divided into seven parts: Part I: Newton’s Laws, Part II: Conservation Laws, Part III: Applications of Newtonian Mechanics, Part IV: Thermodynamics, Part V: Waves and Optics, Part VI: Electricity and Magnetism, and Part VII: Relativity and Quantum Physics. Although I recommend covering the parts in this order (see below), doing so is by no means essential. Each topic is self-contained, and Parts III–VI can be rearranged to suit a teacher’s needs.

Organization Rationale: Thermodynamics is placed before waves because it is a continuation of ideas from mechanics. The key idea in thermodynamics is energy, and moving from mechanics into thermodynamics allows the uninterrupted development of this important idea. Further, waves introduce students to functions of two variables, and the mathematics of waves is more akin to electricity and magnetism than to mechanics. Thus moving from waves to fields to quantum physics provides a gradual transition of ideas and skills.

The purpose of placing optics with waves is to provide a coherent presentation of wave physics, one of the two pillars of classical physics. Optics as it is presented in algebra-based physics makes no use of the properties of electromagnetic fields. There’s little reason other than historical tradition to delay optics until after E&M. The documented difficulties that students have with optics are difficulties with waves, not difficulties with electricity and magnetism. However, the optics chapters are easily deferred until the end of Part VI for teachers who prefer that ordering of topics.

The Student Workbook

A key component of Physics for Scientists and Engineers: A Strategic Approach is the accompanying Student Workbook. The workbook bridges the gap between textbook and homework problems by providing students the opportunity to learn and practice
Teacher Supplements

Most of the teacher supplements and resources for this text are available electronically to qualified adopters on the Instructor Resource Center (IRC). Upon adoption or to preview, please go to www.PearsonSchool.com/Access_Request and select Instructor Resource Center (Option 1). You will be required to complete a brief one-time registration, subject to verification of educator status. Upon verification, access information and instructions will be sent to you via e-mail. Once logged into the IRC, enter your text ISBN in the “Search our Catalog” box at PearsonHigherEd.com/educator to locate your resources.

- The Instructor Guide for Physics for Scientists and Engineers (ISBN 978-0-321-74765-5/0-321-74765-8) offers detailed comments and suggested teaching ideas for every chapter, an extensive review of what has been learned from physics education research, and guidelines for using active-learning techniques in your classroom. This invaluable guide is available on the Instructor Resource DVD, and via download, either from the MasteringPhysics Instructor Area or from the Instructor Resource Center (www.pearsonhighered.com/educator).

- The Instructor Solutions (ISBN 978-0-321-76940-4/0-321-76940-6), provide complete solutions to all the end-of-chapter problems. The solutions follow the four-step Model/Visualize/Solve/Assess procedure used in the Problem-Solving Strategies and in all worked examples. The solutions are available by chapter as editable Word® documents and as PDFs for your own use. Also provided are PDFs of handwritten solutions to all of the exercises in the Student Workbook. All solutions are available only via download, either from the MasteringPhysics Instructor Area or from the Instructor Resource Center (www.pearsonhighered.com/educator).

- The cross-platform Instructor Resource DVD (ISBN 978-0-321-75456-1/0-321-75456-5) provides a comprehensive library of more than 220 applets from ActivPhysics OnLine and 76 PhET simulations, as well as all figures, photos, tables, summaries, and key equations from the textbook in JPEG format. In addition, all the Problem-Solving Strategies, Tactics Boxes, and Key Equations are provided in editable Word format. PowerPoint® Lecture Outlines with embedded Classroom Response System “Clicker” Questions (including reading quizzes) are also provided.

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- **Adoption Access**
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OR

- Visit PearsonSchool.com/Access_Request and select Option 2/3. Adoption access information will be sent to the teacher via email. Students, ask your teacher for access.
MasteringPhysics is the most advanced, educationally effective, and widely used physics homework and tutorial system in the world. Eight years in development, it provides teachers with a library of extensively pre-tested end-of-chapter problems and rich, multipart, multistep tutorials that incorporate a wide variety of answer types, wrong answer feedback and individualized help (comprising hints or simpler sub-problems upon request) all driven by the largest metadatabase of student problem solving in the world. NSF-sponsored published research (and subsequent studies) show that MasteringPhysics has dramatic educational results. MasteringPhysics allows teachers to build wide-ranging homework assignments of just the right difficulty and length, and provides them with efficient tools to analyze in unprecedented detail both class trends and the work of any student.

MasteringPhysics routinely provides instant and individualized feedback and guidance to more than 100,000 students every day. A wide range of tools and support make MasteringPhysics fast and easy for teachers and students to learn to use. Extensive class tests show that by the end of their course, an unprecedented nine of ten students recommend MasteringPhysics as their preferred way to study physics and do homework.

For the third edition of Physics for Scientists and Engineers, MasteringPhysics now has the following functionalities:

- **Learning Outcomes:** In addition to being able to create their own learning outcomes to associate with questions in an assignment, teachers can now select content that is tagged to a large number of publisher-provided learning outcomes. They can also print or export student results based on learning outcomes for their own use or to incorporate into reports for their administration.

- **Quizzing and Testing Enhancements:** These include options to hide item titles, add password protection, limit access to completed assignments, and to randomize question order in an assignment.

- **Math Remediation:** Found within selected tutorials, special links provide just-in-time math help and allow students to brush up on the most important mathematical concepts needed to successfully complete assignments. This new feature links students directly to math review and practice, helping students make the connection between math and physics.

- **Enhanced End-of-Chapter Problems:** A subset of homework problems now offer additional support such as problem-solving strategy hints, relevant math review and practice, links to the eText, and links to the related Video Tutor Solution.

- **ActivPhysics OnLine™** (accessed through the Self Study area within www.masteringphysics.com) provides a comprehensive library of more than 220 tried and tested ActivPhysics core applets updated for web delivery using the latest online technologies. In addition, it provides a suite of highly regarded applet-based tutorials developed by education pioneers Alan Van Heuvelen and Paul D’Alessandris.

  The online exercises are designed to encourage students to confront misconceptions, reason qualitatively about physical processes, experiment quantitatively, and learn to think critically. The highly acclaimed ActivPhysics OnLine companion workbooks help students work through complex concepts and understand them more clearly. The applets from the ActivPhysics OnLine library are also available on the Instructor Resource DVD for this text.

- The **Test Bank** (ISBN 978-0-321-74766-2/0-321-74766-6) contains more than 2,000 high-quality problems, with a range of multiple-choice, true/false, short-answer, and regular homework-type questions. Test files are provided both in TestGen (an easy-to-use, fully networkable program for creating and editing quizzes and exams) and Word format. They are available only via download, either from the MasteringPhysics Instructor Area or from the Instructor Resource Center (www.pearsonhighered.com/educator).

### Student Supplements

The following resources are available for purchase:


- **MasteringPhysics** (www.masteringphysics.com) is a homework, tutorial, and assessment system based on years of research into how students work physics problems and precisely where they need help. Studies show that students who use MasteringPhysics significantly increase their scores compared to hand-written homework. MasteringPhysics achieves this improvement by providing students with instantaneous feedback specific to their wrong answers, simpler sub-problems upon request when they get stuck, and partial credit for their method(s). This individualized, 24/7 Socratic tutoring is recommended by 9 out of 10 students to their peers as the most effective and time-efficient way to study.
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Finally, I am endlessly grateful to my wife Sally for her love, encouragement, and patience, and to our many cats, past and present, who understand clearly that their priority is not deadlines but “Pet me, pet me, pet me.”

Randy Knight, September 2011
rknight@calpoly.edu

Reviewers and Classroom Testers

Special thanks go to our third edition review panel: Kyle Altman, Taner Edis, Kent Fisher, Marty Gelfand, Elizabeth George, Jason Harlow, Bob Jacobsen, David Lee, Gary Morris, Eric Murray, and Bruce Schumm.

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Preface to the Student

From Me to You

The most incomprehensible thing about the universe is that it is comprehensible.
—Albert Einstein

The day I went into physics class it was death.
—Sylvia Plath, The Bell Jar

Let’s have a little chat before we start. A rather one-sided chat, admittedly, because you can’t respond, but that’s OK. I’ve talked with many of your fellow students over the years, so I have a pretty good idea of what’s on your mind.

What’s your reaction to taking physics? Fear and loathing? Uncertainty? Excitement? All of the above? Let’s face it, physics has a bit of an image problem. You’ve probably heard that it’s difficult, maybe downright impossible unless you’re an Einstein. Things that you’ve heard, your experiences in other science courses, and many other factors all color your expectations about what this course is going to be like.

I think it’s fair to say that it will be an intense course. But we can avoid many potential problems and difficulties if we can establish, here at the beginning, what this course is about and what is expected of you—and of me!

Just what is physics, anyway? Physics is a way of thinking about the physical aspects of nature. Physics is not better than art or biology or poetry or religion, which are also ways to think about nature; it’s simply different. One of the things this course will emphasize is that physics is a human endeavor. The ideas presented in this book were not found in a cave or conveyed to us by aliens; they were discovered and developed by real people engaged in a struggle with real issues. I hope to convey to you something of the history and the process by which we have come to accept the principles that form the foundation of today’s science and engineering.

You might be surprised to hear that physics is not about “facts.” Oh, not that facts are unimportant, but physics is far more focused on discovering relationships that exist between facts and patterns that exist in nature than on learning facts for their own sake. As a consequence, there’s not a lot of memorization when you study physics. Some—there are still definitions and equations to learn—but less than in many other courses. Our emphasis, instead, will be on thinking and reasoning. This is important to factor into your expectations for the course.

Perhaps most important of all, physics is not math! Physics is much broader. We’re going to look for patterns and relationships in nature, develop the logic that relates different ideas, and search for the reasons why things happen as they do. In doing so, we’re going to stress qualitative reasoning, pictorial and graphical reasoning, and reasoning by analogy. And yes, we will use math, but it’s just one tool among many.

It will save you much frustration if you’re aware of this physics–math distinction up front. Many of you, I know, want to find a formula and plug numbers into it—that is, to do a math problem. We’ll certainly do many calculations, but the specific numbers are usually the last and least important step in the analysis.
Preface to the Student

Physics is about recognizing patterns. For example, the top photograph is an x-ray diffraction pattern showing how a focused beam of x rays spreads out after passing through a crystal. The bottom photograph shows what happens when a focused beam of electrons is shot through the same crystal. What does the obvious similarity in these two photographs tell us about the nature of light and the nature of matter?

As you study, you’ll sometimes be baffled, puzzled, and confused. That’s perfectly normal and to be expected. Making mistakes is OK too if you’re willing to learn from the experience. No one is born knowing how to do physics any more than he or she is born knowing how to play the piano or shoot basketballs. The ability to do physics comes from practice, repetition, and struggling with the ideas until you “own” them and can apply them yourself in new situations. There’s no way to make learning effortless, at least for anything worth learning, so expect to have some difficult moments ahead. But also expect to have some moments of excitement at the joy of discovery. There will be instants at which the pieces suddenly click into place and you know that you understand a powerful idea. There will be times when you’ll surprise yourself by successfully working a difficult problem that you didn’t think you could solve. My hope, as an author, is that the excitement and sense of adventure will far outweigh the difficulties and frustrations.

Getting the Most Out of Your Course

Many of you, I suspect, would like to know the “best” way to study for this course. There is no best way. People are different, and what works for one student is less effective for another. But I do want to stress that reading the text is vitally important. Class time will be used to clarify difficulties and to develop tools for using the knowledge, but your teacher will not use class time simply to repeat information in the text. The basic knowledge for this course is written down on these pages, and the number-one expectation is that you will read carefully and thoroughly to find and learn that knowledge.

Despite there being no best way to study, I will suggest one way that is successful for many students. It consists of the following four steps:

1. **Read each chapter before it is discussed in class.** I cannot stress too strongly how important this step is. Class attendance is much more effective if you are prepared. When you first read a chapter, focus on learning new vocabulary, definitions, and notation. There’s a list of terms and notations at the end of each chapter. Learn them! You won’t understand what’s being discussed or how the ideas are being used if you don’t know what the terms and symbols mean.

2. **Participate actively in class.** Take notes, ask and answer questions, and participate in discussion groups. There is ample scientific evidence that active participation is much more effective for learning science than passive listening.

3. **After class, go back for a careful re-reading of the chapter.** In your second reading, pay closer attention to the details and the worked examples. Look for the logic behind each example (I’ve highlighted this to make it clear), not just at what formula is being used. Do the Student Workbook exercises for each section as you finish your reading of it.

4. **Finally, apply what you have learned to the homework problems at the end of each chapter.** I strongly encourage you to form a study group with two or three classmates. There’s good evidence that students who study regularly with a group do better than the rugged individualists who try to go it alone.

Did someone mention a workbook? The companion Student Workbook is a vital part of the course. Its questions and exercises ask you to reason qualitatively, to use
graphical information, and to give explanations. It is through these exercises that you will learn what the concepts mean and will practice the reasoning skills appropriate to the chapter. You will then have acquired the baseline knowledge and confidence you need before turning to the end-of-chapter homework problems. In sports or in music, you would never think of performing before you practice, so why would you want to do so in physics? The workbook is where you practice and work on basic skills.

Many of you, I know, will be tempted to go straight to the homework problems and thenthumb through the text looking for a formula that seems like it will work. That approach will not succeed in this course, and it’s guaranteed to make you frustrated and discouraged. Very few homework problems are of the “plug and chug” variety where you simply put numbers into a formula. To work the homework problems successfully, you need a better study strategy—either the one outlined above or your own—that helps you learn the concepts and the relationships between the ideas.

**Getting the Most Out of Your Textbook**

Your textbook provides many features designed to help you learn the concepts of physics and solve problems more effectively.

- **TACTICS BOXES** give step-by-step procedures for particular skills, such as interpreting graphs or drawing special diagrams. Tactics Box steps are explicitly illustrated in subsequent worked examples, and these are often the starting point of a full Problem-Solving Strategy.

---

**TACTICS BOX 5.1** Drawing a free-body diagram

1. **Identify all forces acting on the object.** This step was described in Tactics Box 5.2.
2. **Draw a coordinate system.** Use the axes defined in your pictorial representation.
3. **Represent the object as a dot at the origin of the coordinate axes.** This is the particle model.
4. **Draw vectors representing each of the identified forces.** This was described in Tactics Box 5.1. Be sure to label each force vector.
5. **Draw and label the net force vector \( \vec{F}_{\text{net}} \).** Draw this vector beside the diagram, not on the particle. Or, if appropriate, write \( \vec{F}_{\text{net}} = 0 \). Then check that \( \vec{F}_{\text{net}} \) points in the same direction as the acceleration vector \( \vec{a} \) on your motion diagram.

**Exercise 24-25**

---

**TACTICS BOX 32.2** Evaluating line integrals

1. **If \( \vec{B} \) is everywhere perpendicular to a line, the line integral of \( \vec{B} \) is**

\[
\int_i^f \vec{B} \cdot dl = 0
\]

2. **If \( \vec{B} \) is everywhere tangent to a line of length \( l \) and has the same magnitude \( B \) at every point, then**

\[
\int_i^f \vec{B} \cdot dl = Bl
\]

**Exercises 23-24**
PROBLEM-SOLVING STRATEGIES are provided for each broad class of problems—problems characteristic of a chapter or group of chapters. The strategies follow a consistent four-step approach to help you develop confidence and proficient problem-solving skills: MODEL, VISUALIZE, SOLVE, ASSESS.

**Dynamics problems**

**MODEL**

Make simplifying assumptions.

**VISUALIZE**

Draw a pictorial representation.

- Show important points in the motion with a sketch, establish a coordinate system, define symbols, and identify what the problem is trying to find.
- Use a motion diagram to determine the object’s acceleration vector $\overrightarrow{a}$.
- Identify all forces acting on the object at this instant and show them on a free-body diagram.
- It’s OK to go back and forth between these steps as you visualize the situation.

**SOLVE**

The mathematical representation is based on Newton’s second law:

$$\overrightarrow{F}_{\text{net}} = \sum \overrightarrow{F} = ma$$

The vector sum of the forces is found directly from the free-body diagram. Depending on the problem, either

- Solve for the acceleration, then use kinematics to find velocities and positions; or
- Use kinematics to determine the acceleration, then solve for unknown forces.

**ASSESS**

Check that your result has the correct units, is reasonable, and answers the question.

---

**Worked EXAMPLES** illustrate good problem-solving practices through the consistent use of the four-step problem-solving approach and, where appropriate, the Tactics Box steps. The worked examples are often very detailed and carefully lead you through the reasoning behind the solution as well as the numerical calculations. A careful study of the reasoning will help you apply the concepts and techniques to the new and novel problems you will encounter in homework assignments and on exams.

**NOTE** paragraphs alert you to common mistakes and point out useful tips for tackling problems.

**STOP TO THINK** questions embedded in the chapter allow you to quickly assess whether you’ve understood the main idea of a section. A correct answer will give you confidence to move on to the next section. An incorrect answer will alert you to re-read the previous section.

**Blue annotations** on figures help you better understand what the figure is showing. They will help you to interpret graphs; translate between graphs, math, and pictures; grasp difficult concepts through a visual analogy; and develop many other important skills.

**Pencil sketches** provide practical examples of the figures you should draw yourself when solving a problem.

---

Pencil-sketch **FIGURE** showing a toboggan going down a hill and its energy bar chart.
Each chapter begins with a Chapter Preview, a visual outline of the chapter ahead with recommendations of important topics you should review from previous chapters. A few minutes spent with the Preview will help you organize your thoughts so as to get the most out of reading the chapter.

Schematic Chapter Summaries help you organize what you have learned into a hierarchy, from general principles (top) to applications (bottom). Side-by-side pictorial, graphical, textual, and mathematical representations are used to help you translate between these key representations.

Part Overviews and Summaries provide a global framework for what you are learning. Each part begins with an overview of the chapters ahead and concludes with a broad summary to help you to connect the concepts presented in that set of chapters. KNOWLEDGE STRUCTURE tables in the Part Summaries, similar to the Chapter Summaries, help you to see the forest rather than just the trees.

Now that you know more about what is expected of you, what can you expect of me? That’s a little trickier because the book is already written! Nonetheless, the book was prepared on the basis of what I think my students throughout the years have expected—and wanted—from their physics textbook. Further, I’ve listened to the extensive feedback I have received from thousands of students like you, and their teachers, who used the first and second editions of this book.

You should know that these course materials are based on extensive research about how students learn physics and the challenges they face. The effectiveness of many of the exercises has been demonstrated through extensive class testing. I’ve written the book in an informal style that I hope you will find appealing and that will encourage you to do the reading. And, finally, I have endeavored to make clear not only that physics, as a technical body of knowledge, is relevant to your profession but also that physics is an exciting adventure of the human mind.

I hope you’ll enjoy the time we’re going to spend together.
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About the Author

Randy Knight has taught introductory physics for over 30 years at Ohio State University and California Polytechnic University, where he is currently Professor of Physics. Professor Knight received a bachelor’s degree in physics from Washington University in St. Louis and a Ph.D. in physics from the University of California, Berkeley. He was a post-doctoral fellow at the Harvard-Smithsonian Center for Astrophysics before joining the faculty at Ohio State University. It was at Ohio State that he began to learn about the research in physics education that, many years later, led to this book.

Professor Knight’s research interests are in the field of lasers and spectroscopy, and he has published over 25 research papers. He also directs the environmental studies program at Cal Poly, where, in addition to introductory physics, he teaches classes on energy, oceanography, and environmental issues. When he’s not in the classroom or in front of a computer, you can find Randy hiking, sea kayaking, playing the piano, or spending time with his wife Sally and their seven cats.
Introduction

Journey into Physics

Said Alice to the Cheshire cat,
"Cheshire-Puss, would you tell me, please, which way I ought to go from here?"
"That depends a good deal on where you want to go," said the Cat.
"I don’t much care where—" said Alice.
"Then it doesn’t matter which way you go," said the Cat.
—Lewis Carroll, Alice in Wonderland

Have you ever wondered about questions such as

- Why is the sky blue?
- Why is glass an insulator but metal a conductor?
- What, really, is an atom?

These are the questions of which physics is made. Physicists try to understand the universe in which we live by observing the phenomena of nature—such as the sky being blue—and by looking for patterns and principles to explain these phenomena. Many of the discoveries made by physicists, from electromagnetic waves to nuclear energy, have forever altered the ways in which we live and think.

You are about to embark on a journey into the realm of physics. It is a journey in which you will learn about many physical phenomena and find the answers to questions such as the ones posed above. Along the way, you will also learn how to use physics to analyze and solve many practical problems.

As you proceed, you are going to see the methods by which physicists have come to understand the laws of nature. The ideas and theories of physics are not arbitrary; they are firmly grounded in experiments and measurements. By the time you finish this text, you will be able to recognize the evidence upon which our present knowledge of the universe is based.

Which Way Should We Go?

We are rather like Alice in Wonderland, here at the start of the journey, in that we must decide which way to go. Physics is an immense body of knowledge, and without specific goals it would not much matter which topics we study. But unlike Alice, we do have some particular destinations that we would like to visit.

The physics that provides the foundation for all of modern science and engineering can be divided into three broad categories:

- Particles and energy.
- Fields and waves.
- The atomic structure of matter.

A particle, in the sense that we’ll use the term, is an idealization of a physical object. We will use particles to understand how objects move and how they interact with each other. One of the most important properties of a particle or a collection of particles is energy. We will study energy both for its value in understanding physical processes and because of its practical importance in a technological society.
Particles are discrete, localized objects. Although many phenomena can be understood in terms of particles and their interactions, the long-range interactions of gravity, electricity, and magnetism are best understood in terms of fields, such as the gravitational field and the electric field. Rather than being discrete, fields spread continuously through space. Much of the second half of this book will be focused on understanding fields and the interactions between fields and particles.

Certainly one of the most significant discoveries of the past 500 years is that matter consists of atoms. Atoms and their properties are described by quantum physics, but we cannot leap directly into that subject and expect that it would make any sense. To reach our destination, we are going to have to study many other topics along the way—rather like having to visit the Rocky Mountains if you want to drive from New York to San Francisco. All our knowledge of particles and fields will come into play as we end our journey by studying the atomic structure of matter.

The Route Ahead

Here at the beginning, we can survey the route ahead. Where will our journey take us? What scenic vistas will we view along the way?

Parts I and II, Newton’s Laws and Conservation Laws, form the basis of what is called classical mechanics. Classical mechanics is the study of motion. (It is called classical to distinguish it from the modern theory of motion at the atomic level, which is called quantum mechanics.) The first two parts of this textbook establish the basic language and concepts of motion. Part I will look at motion in terms of particles and forces. We will use these concepts to study the motion of everything from accelerating sprinters to orbiting satellites. Then, in Part II, we will introduce the ideas of momentum and energy. These concepts—especially energy—will give us a new perspective on motion and extend our ability to analyze motion.

Part III, Applications of Newtonian Mechanics, will pause to look at four important applications of classical mechanics: Newton’s theory of gravity, rotational motion, oscillatory motion, and the motion of fluids. Only oscillatory motion is a prerequisite for later chapters. Your teacher may choose to cover some or all of the other chapters, depending upon the time available, but your study of Parts IV–VII will not be hampered if these chapters are omitted.

Part IV, Thermodynamics, extends the ideas of particles and energy to systems such as liquids and gases that contain vast numbers of particles. Here we will look for connections between the microscopic behavior of large numbers of atoms and the macroscopic properties of bulk matter. You will find that some of the properties of gases that you know from chemistry, such as the ideal gas law, turn out to be direct consequences of the underlying atomic structure of the gas. We will also expand the concept of energy and study how energy is transferred and utilized.
Waves are ubiquitous in nature, whether they be large-scale oscillations like ocean waves, the less obvious motions of sound waves, or the subtle undulations of light waves and matter waves that go to the heart of the atomic structure of matter. In Part V, Waves and Optics, we will emphasize the unity of wave physics and find that many diverse wave phenomena can be analyzed with the same concepts and mathematical language. Light waves are of special interest, and we will end this portion of our journey with an exploration of optical instruments, ranging from microscopes and telescopes to that most important of all optical instruments—your eye.

Part VI, Electricity and Magnetism, is devoted to the electromagnetic force, one of the most important forces in nature. In essence, the electromagnetic force is the "glue" that holds atoms together. It is also the force that makes this the "electronic age." We'll begin this part of the journey with simple observations of static electricity. Bit by bit, we'll be led to the basic ideas behind electrical circuits, to magnetism, and eventually to the discovery of electromagnetic waves.

Part VII is Relativity and Quantum Physics. We'll start by exploring the strange world of Einstein's theory of relativity, a world in which space and time aren't quite what they appear to be. Then we will enter the microscopic domain of atoms, where the behaviors of light and matter are at complete odds with what our common sense tells us is possible. Although the mathematics of quantum theory quickly gets beyond the level of this text, and time will be running out, you will see that the quantum theory of atoms and nuclei explains many of the things that you learned simply as rules in chemistry.

We will not have visited all of physics on our travels. There just isn't time. Many exciting topics, ranging from quarks to black holes, will have to remain unexplored. But this particular journey need not be the last. As you finish this text, you will have the background and the experience to explore new topics further in more advanced courses or for yourself.

With that said, let us take the first step.