

knight | jones | field

college physics

a strategic approach 4e

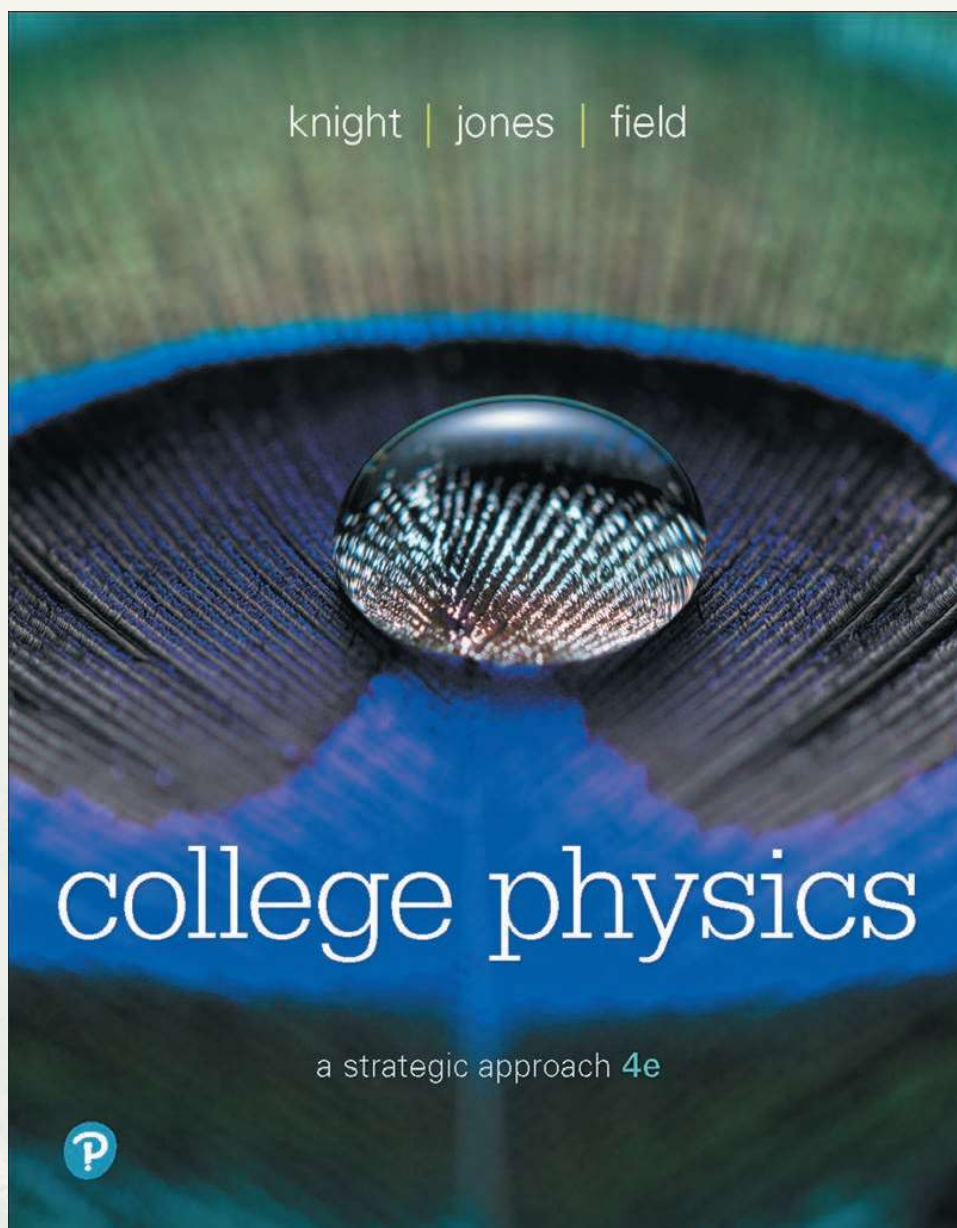
AP[®] Edition



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ENGAGE today's students

For the fourth edition of *College Physics: A Strategic Approach*, we expand our focus from HOW students learn physics to WHY students study physics. We now make connections to biology and other sciences throughout the text to keep students engaged, presenting content that is relevant to today's students. This new edition is one of the best college physics book on the market for non-physics majors.



More connections to life science

Build students' problem-solving skills in a context they care about while using real-life data and examples to keep their interest piqued.

13.7 The Circulatory System

The Arteries and Capillaries

In the human body, blood pumped from the heart to the body starts its journey in a single large artery, the aorta. The flow then branches into smaller blood vessels, the large arteries that feed the head, the trunk, and the limbs. These branch into still smaller arteries, which then branch into a network of much smaller arterioles, which branch further into the capillaries. **FIGURE 13.37** shows a schematic outline of the circulation, with average values for the diameters of the individual vessels, the total cross-section area of all of each type of vessel considered together, and the pressure in these vessels, assuming that the person is lying down so that there is no pressure change due to differences in elevation.

This preserved section of blood vessels shows the tremendous increase in number and in total area as blood vessels branch from large arteries to arterioles. One large artery gives rise to thousands of smaller vessels.



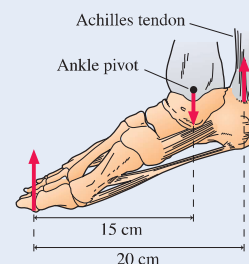
NEW! Topics of interest to life science students, such as the nature of the drag force at different scales and qualitative and quantitative descriptions of diffusion, provide current coverage of relevant topics based on the evolving consensus in the introductory physics for the life sciences community.

NEW! Material stressing the application of physics to life sciences includes structural color in animals and plants, the electric sense of different animals, the circulatory system (13.7) and on forces and torques in the body (8.5).

8.5 Forces and Torques in the Body

Let's take your foot as the object of interest. When you stand on tiptoe, your foot pivots about your ankle. As shown in **FIGURE 8.27**, the forces on one foot are an upward force on your toes from the floor, a downward force on your ankle from the lower leg bone, and an upward force on the heel of your foot from your Achilles tendon. Suppose a 61 kg woman stands on one foot, on tiptoe, with the sole of her foot making a 25° angle with the floor; the distances are as shown in Figure 8.27. What is the magnitude of the tension force in the tendon? By what fraction does this force exceed the woman's weight? What is the magnitude of the force in the ankle joint?

FIGURE 8.27 Forces on the foot when standing on tiptoe.



create relevance to students' lives

EXAMPLE 2.16

Finding the height of a leap

A springbok is an antelope found in southern Africa that gets its name from its remarkable jumping ability. When a springbok is startled, it will leap straight up into the air—a maneuver called a “prong.”




A particular springbok goes into a crouch to perform a prong. It then extends its legs forcefully, accelerating at 35 m/s^2 for 0.70 m as its legs straighten. Legs fully extended, it leaves the ground and rises into the air.

- At what speed does the springbok leave the ground?
- How high does it go?

STRATEGIZE This is a two-part problem. In the first phase of its motion, the springbok accelerates upward, reaching some maximum speed just as it leaves the ground. As soon as it does so, the springbok is subject to only the force of gravity, so it is in free fall. For both phases, we will use the constant-acceleration equations from Synthesis 2.1.

NEW! STRATEGIZE step in Examples shows students the “big picture” view before delving into the details. Classroom testing of this addition has shown it to be popular with students and effective in teaching problem-solving skills.

NEW! End-of-chapter problem sets now include real-life data and examples, helping students build transferable skills for their future courses and careers.

8.  A hippo's body is 4.0 m long with front and rear feet located as in Figure P8.8. The hippo carries 60% of its weight on its front feet. How far from its tail is the hippo's center of gravity?

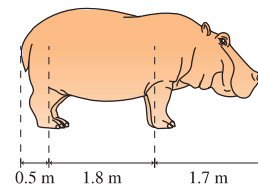


FIGURE P8.8

NEW! Learning Objectives, keyed to relevant end-of-chapter problems, help students check their understanding and guide them in choosing appropriate problems to optimize their study time.

Learning Objectives After studying this chapter, you should be able to:

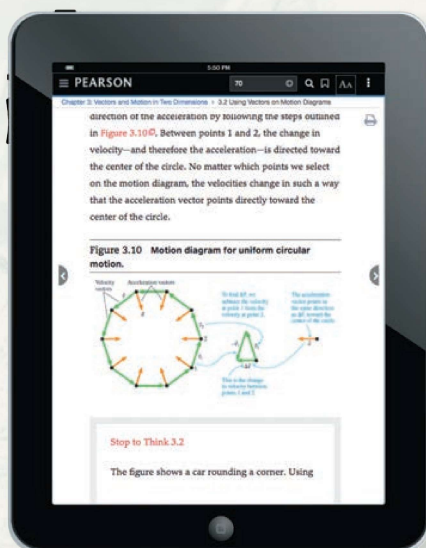
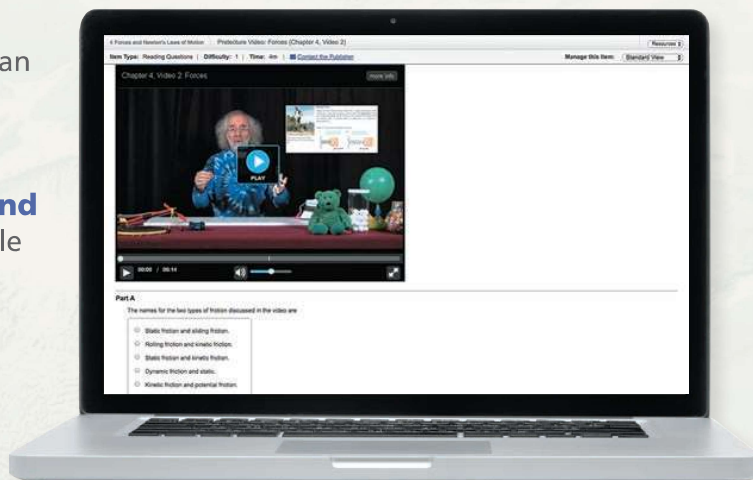
- Use motion diagrams to interpret motion. *Conceptual Question 2.3; Problems 2.1, 2.2, 2.59*
- Use and interpret motion graphs. *Conceptual Questions 2.5, 2.13; Problems 2.4, 2.18, 2.19, 2.22, 2.62*
- Calculate the velocity of an object. *Conceptual Question 2.9; Problems 2.8, 2.15, 2.57*
- Solve problems about an object in uniform motion. *Problems 2.9, 2.10, 2.11, 2.13, 2.58*
- Calculate the acceleration of an object. *Problems 2.25, 2.27, 2.32, 2.33, 2.72*
- Determine and interpret the sign of acceleration. *Conceptual Questions 2.2, 2.8; Problem 2.50*
- Use the problem-solving approach to solve problems of motion with constant acceleration and free fall. *Problems 2.36, 2.40, 2.41, 2.47, 2.52, 2.75*

Prepare students for engagement



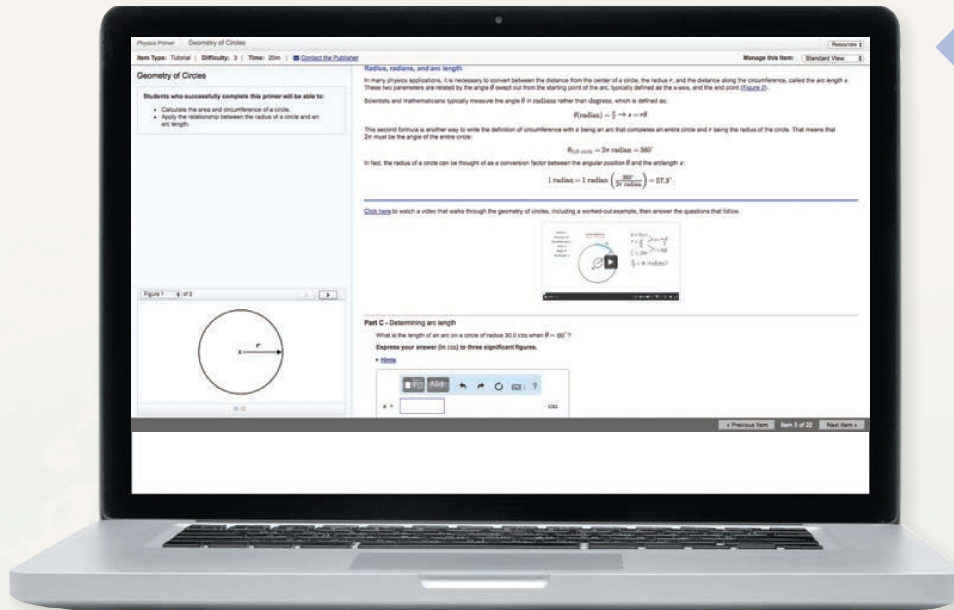
NEW! What the Physics? Videos bring relatable content to engage students with what they are learning and promote curiosity for natural phenomena. These short videos present visually stimulating physical phenomena, pause throughout to address misconceptions, and ask conceptual questions about the physics at hand. Quantitative questions follow some of the videos and will be assignable in Mastering™ Physics and embedded in the eText.

Prelecture Videos, presented by co-author Brian Jones, expand on the Chapter Previews, giving context, examples, and a chance for students to practice the concepts they are studying via short multiple-choice questions. **NEW! Qualitative and Quantitative prelecture videos** now available with assessment as well!



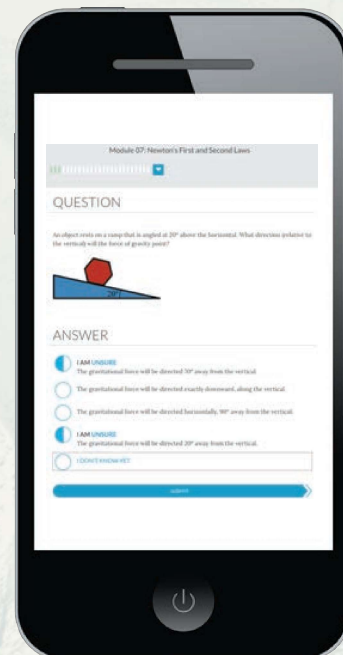
NEW! eText, optimized for mobile, seamlessly integrates videos and other rich media with the text and gives students access to their textbook anytime, anywhere. eText is available with Mastering Physics when packaged with new books, or as an upgrade students can purchase online.

in lecture with interactive media

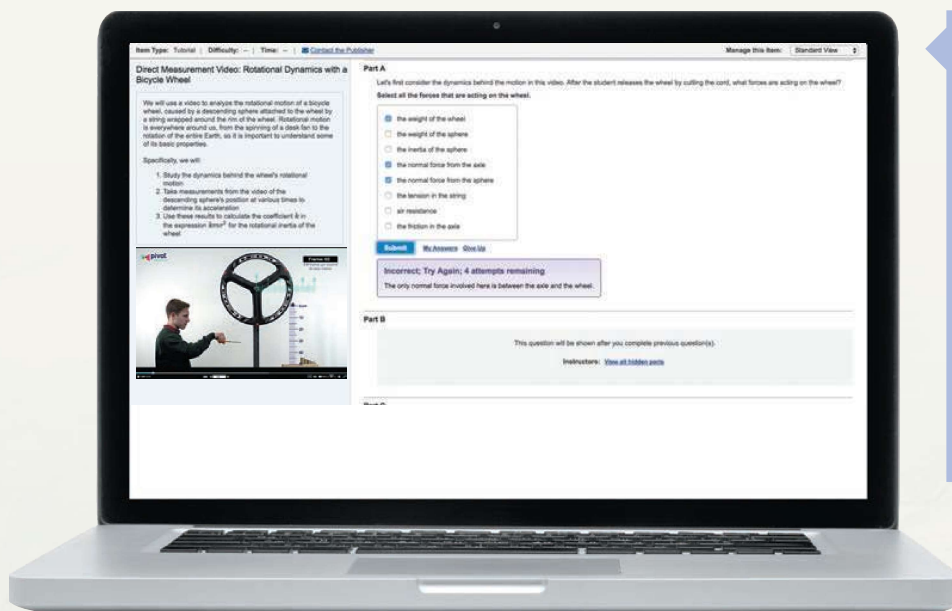


NEW! The Physics Primer relies on videos, hints, and feedback to refresh students' math skills in the context of physics and prepare them for success in the course. These tutorials can be assigned before the course begins as well as throughout the course. They ensure students practice and maintain their math skills, while tying together mathematical operations and physics analysis.

Dynamic Study Modules (DSMs) help students study effectively on their own by continuously assessing their activity and performance in real time and adapting to their level of understanding. The content focuses on definitions, units, and the key relationships for topics across all of mechanics and electricity and magnetism.



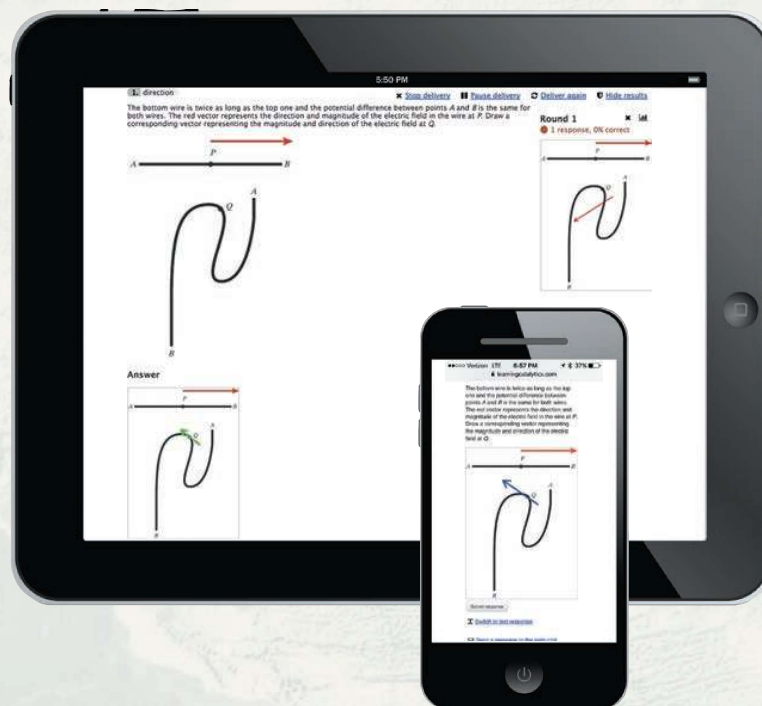
Enhance students' understanding



NEW! Direct Measurement Videos are short videos that show real situations of physical phenomena. Grids, rulers, and frame counters appear as overlays, helping students to make precise measurements of quantities such as position and time. Students then apply these quantities along with physics concepts to solve problems and answer questions about the motion of the objects in the video.

Learning Catalytics™ helps generate class discussion, customize lectures, and promote peer-to-peer learning with real-time analytics. Learning Catalytics acts as a student response tool that uses students' smartphones, tablets, or laptops to engage them in more interactive tasks and thinking:

- **NEW!** Upload a full PowerPoint® deck for easy creation of slide questions.
- Monitor responses to find out where your students are struggling.
- Rely on real-time data to adjust your teaching strategy.
- Automatically group students for discussion, teamwork, and peer-to-peer learning.



Supplements further enhance the learning experience

For the Student

The following resources are available for purchase:

Student Workbook (9780134609898)

A key component of *College Physics: 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 skills prior to using those skills in quantitative end-of-chapter problems, much as a musician practices technique separately from performance pieces. The workbook exercises, which are keyed to each section of the textbook, focus on developing specific skills, ranging from identifying forces and drawing free-body diagrams to interpreting field diagrams.

Student Solution Manuals

(Chs. 1–16; 9780134704197) (Chs. 17–30; 9780134724799)

These solutions manuals contain detailed solutions to all of the odd-numbered end-of-chapter problems from the textbook.

10-8 CHAPTER 10: Energy and Work

10.6 Potential Energy

17. Before we use a 1 kg object that is initially 1 m above the ground and rises to a height of 2 m. Apply and Rummy each measure its position but use a different coordinate system to do so. Fill in the table to show the initial and final gravitational potential energies and ΔU as measured by Apply and Rummy.

	U_i	U_f	ΔU
Apply			
Rummy			

18. Three balls of equal mass are fired simultaneously with equal speeds from the same height above the ground. Ball 1 is fired straight up, ball 2 is fired straight down, and ball 3 is fired horizontally. Rank in order, from largest to smallest, their speeds v_1 , v_2 , and v_3 as they hit the ground.

Order: _____

Explanation: _____

19. Below are shown three frictionless tracks. A block is released from rest at the position shown on the left. To which point does the block make it on the right before reversing direction and sliding back? Point C is the same height as the starting position.

Match a to _____ Match b to _____ Match c to _____

For the Teacher

NEW! Ready-to-Go Teaching Modules

(Online only) Created for and by instructors, make use of teaching tools for before, during, and after class, including new ideas for in-class activities. The modules incorporate the best that the text, Mastering Physics, and Learning Catalytics™ have to offer and guide instructors through using these resources in the most effective way. The modules can be accessed through the Instructor Resources Area of Mastering Physics and as pre-built, customizable assignments.

Instructor's Solutions Manual (Online Only)

This comprehensive solutions manual contains complete solutions to all end-of-chapter questions and problems.

TestGen Test Bank (Online Only)

The Test Bank 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 in both TestGen and Word formats.

Instructor's Resource Materials (Online Only)

All art, photos, and tables from the book are available in JPEG format and as modifiable PowerPoints™. In addition, instructors can access lecture outlines as well as "clicker" questions in PowerPoint format, editable content for key features, all the instructor's resources listed above, and solutions to the Student Workbook. Materials are accessible to download from the Instructor Resource area of Mastering Physics.

Knigh, Jones, Field's
College Physics: A Strategic Approach, 4/e
Ready-To-Go Teaching Modules

Ready-to-Go Teaching Modules created for and by instructors make use of teaching tools for before, during, and after class, including new ideas for in-class activities.

The modules incorporate the best that the text, Mastering Physics™, and Learning Catalytics have to offer and guide instructors through using these resources in the most effective way.

The modules can be accessed through the Instructor Resources area of Mastering Physics.

- CHAPTER 1: Force and Motion
- CHAPTER 2: Representing Motion
- CHAPTER 3: Motion in One Dimension
- CHAPTER 4: Vectors and Motion in Two Dimensions
- CHAPTER 5: Forces and Newton's Laws of Motion

Mastering Physics Access

Mastering Physics

Upon textbook purchase, students and teachers are granted access to Mastering Physics with Pearson eText. High school teachers can obtain preview or adoption access to Mastering Physics in one of the following ways:

Preview Access

- Teachers can request preview access online by visiting www.PearsonSchool.com/Access_Request. Select Science, choose Initial Access, and complete the form under Option 2. Preview Access information will be sent to the teacher via e-mail.

Adoption Access

- With the purchase of this program, a Pearson Adoption Access Card with Instructor Manual will be delivered with your textbook purchase. (ISBN: 978-0-13-354087-1)
- Ask your sales representative for a Pearson Adoption Access Card with Instructor Manual. (ISBN: 978-0-13-354087-1)

OR

- Visit PearsonSchool.com/Access_Request, select Science, choose Initial Access, and complete the form under Option 3—MyLab/Mastering Class Adoption Access. Teacher and Student access information will be sent to the teacher via e-mail.

Students, ask your teacher for access.

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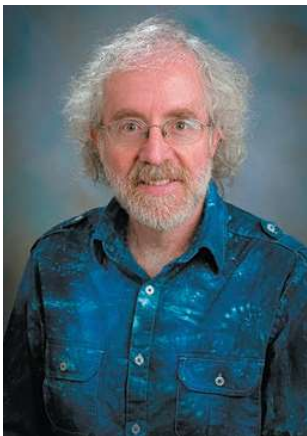
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About the Authors



Randy Knight taught introductory physics for 32 years at Ohio State University and California Polytechnic State University, where he is Professor Emeritus of Physics. Professor Knight received a Ph.D. in physics from the University of California, Berkeley and 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 *Five Easy Lessons: Strategies for Successful Physics Teaching* and this book, as well as *Physics for Scientists and Engineers: A Strategic Approach*. Professor Knight's research interests are in the fields of laser spectroscopy and environmental science. When he's not in front of a computer, you can find Randy hiking, sea kayaking, playing the piano, or spending time with his wife Sally and their five cats.



Brian Jones has won several teaching awards at Colorado State University during his 30 years teaching in the Department of Physics. His teaching focus in recent years has been the College Physics class, including writing problems for the MCAT exam and helping students review for this test. In 2011, Brian was awarded the Robert A. Millikan Medal of the American Association of Physics Teachers for his work as director of the Little Shop of Physics, a hands-on science outreach program. He is actively exploring the effectiveness of methods of informal science education and how to extend these lessons to the college classroom. Brian has been invited to give workshops on techniques of science instruction throughout the United States and in Belize, Chile, Ethiopia, Azerbaijan, Mexico, Slovenia, Norway, and Namibia. Brian and his wife Carol have dozens of fruit trees and bushes in their yard, including an apple tree that was propagated from a tree in Isaac Newton's garden.



Stuart Field has been interested in science and technology his whole life. While in school he built telescopes, electronic circuits, and computers. After attending Stanford University, he earned a Ph.D. at the University of Chicago, where he studied the properties of materials at ultralow temperatures. After completing a postdoctoral position at the Massachusetts Institute of Technology, he held a faculty position at the University of Michigan. Currently at Colorado State University, Stuart teaches a variety of physics courses, including algebra-based introductory physics, and was an early and enthusiastic adopter of Knight's *Physics for Scientists and Engineers*. Stuart maintains an active research program in the area of superconductivity. Stuart enjoys Colorado's great outdoors, where he is an avid mountain biker; he also plays in local ice hockey leagues.

Preface to the Instructor

In 2006, we published *College Physics: A Strategic Approach*, a new algebra-based physics textbook for students majoring in the biological and life sciences, architecture, natural resources, and other disciplines. As the first such book built from the ground up on research into how students can more effectively learn physics, it quickly gained widespread critical acclaim from professors and students alike. For this fourth edition, we have continued to build on the research-proven instructional techniques introduced in the first edition while working to make the book more useful for instructors, more relevant to the students who use it, and more connected to the other subjects they study.

Objectives

Our primary goals in writing *College Physics: A Strategic Approach* are:

- To provide students with a textbook that's a more manageable size, less encyclopedic in its coverage, and better designed for learning.
- To integrate proven techniques from physics education research into the classroom in a way that accommodates a range of teaching and learning styles.
- To help students develop both quantitative reasoning skills and solid conceptual understanding, with special focus on concepts well documented to cause learning difficulties.
- To help students develop problem-solving skills and confidence in a systematic manner using explicit and consistent tactics and strategies.
- To motivate students by integrating real-world examples that are relevant to their majors—especially from biology, sports, medicine, the animal world—and that build upon their everyday experiences.
- To utilize proven techniques of visual instruction and design from educational research and cognitive psychology that improve student learning and retention and address a range of learner styles.

A more complete explanation of these goals and the rationale behind them can be found in Randy Knight's paperback book, *Five Easy Lessons: Strategies for Successful Physics Teaching*. Available for purchase. (ISBN 978-0-805-38702-5)

What's New to This Edition

In previous editions of the text, we focused on *how* students learn physics. Each chapter was built from the ground up to present concepts and problem-solving strategies in an engaging and effective manner. In this edition, we are focusing on *why* students learn physics. This is a question our students often ask. Why should a biology major take physics? A student planning a career in medicine? This book is for a physics course, but it's a course that will generally be taken by students in other fields.

The central goal of this edition is to make the text more relatable to the students who will use it, to add examples, explanations, and problems that show physics at work in contexts the students will find engaging. We've considered extensive feedback from scores of instructors and thousands of students as we worked to enhance and improve the text, figures, and end-of-chapter problems. Instructors need not be specialists in the life sciences or other fields to appreciate the new material. We've done the work to connect physics to other disciplines so that instructors can use this material to engage their students while keeping their focus on the basic physics.

Making the text more relatable meant making significant changes throughout the book. These edits aren't cosmetic add-ons; they reflect a thorough reworking of each chapter. Changes include:

- Guided by an evolving consensus in the Introductory Physics for the Life Sciences community, we have included **new sections** on the nature of the drag force at different scales, qualitative and quantitative descriptions of diffusion, and other topics of interest to life science students.
- We have added a great deal of **new material** that stresses the application of physics to life science topics. For example, we have expanded our treatment of vision and vision correction, included new material on structural color in animals and plants and the electric sense of different animals, and added new sections on the circulatory system and on forces and torques in the body.
- We have made **new connections** between physics topics and other courses that students are likely to take. For example, a new section connects the concept of the conservation of energy to topics from chemistry, including ionization energy and the role of catalysts in reactions. We have continued this approach when we introduced the concept of electric potential energy.
- Hundreds of **new end-of-chapter questions and problems** show physics at work in realistic, interesting situations. We have replaced problems that are artificial and abstract with problems that use real data from research in life science fields, problems that show the physics behind modern technologies, and problems that use physics to explore everyday phenomena. We have used the wealth of data from Mastering™ Physics to make sure that we have problems of a wide range of difficulties for each topic and problem-solving approach. A rigorous blind-solving and accuracy cross-checking process has been used to check all new problems to be sure that they are clearly worded and correct in all details, that they are accompanied by carefully worked out solutions.
- **New examples** throughout the book use the concepts of the chapters to explore realistic situations of interest to the students—from how bees use electric fields to locate promising flowers to how a study of force and torque in the jaw explains why dogs have long snouts and cats don't.
- We have changed the **photos and captions** at the starts of the chapters and parts of the text to better interest and engage students. The questions that are raised at the starts of the chapters aren't rhetorical; they are questions that will be answered in the flow of the chapter.

We have also made a number of changes to make the text an even more effective tool for students:

- A new **STRATEGIZE** step in examples shows students the “big picture” view before we delve into the details. Classroom testing of this addition has shown it to be quite popular with students, and quite effective in teaching problem-solving skills.
- **Key Concept figures** encourage students to actively engage with key or complex figures by asking them to reason with a related STOP TO THINK question.
- Additional **STOP TO THINK questions** provide students with more crucial practice and concept checks as they go through the chapters. The solutions to these questions have been moved to a more prominent location.
- We now provide **Learning Objectives** keyed to relevant end-of-chapter problems to help students check their understanding and guide them in choosing appropriate problems to optimize their study time.
- **Streamlined text and figures** tighten and focus the presentation to more closely match student needs. We've scrutinized every figure, caption, discussion, and photo in order to enhance their clarity and focus their role.
- Increased emphasis on **critical thinking, modeling, and reasoning**, both in worked examples and in end-of-chapter problems, promotes these key skills. These skills are especially important for students who are taking the MCAT exam.

- Expanded use of **realistic and real-world data** ensures students can make sense of answers that are grounded in the real world. Our examples and problems use real numbers and real data; they test different types of reasoning using equations, ratios, and graphs.

We have made many small changes to the flow of the text throughout, streamlining derivations and discussions, providing more explanation for complex concepts and situations, and reordering and reorganizing material so that each section and each chapter have a clearer focus. We have updated our treatment of entropy and the second law to better match current thinking. We have reordered the presentation of material on motion in two dimensions to be more logical. Every chapter has significant and meaningful changes, making this course especially relevant for today's students.

We know that students increasingly rely on sources of information beyond the text, and instructors are looking for quality resources that prepare students for engagement in lecture. The text will always be the central focus, but we have added additional media elements closely tied to the text that will enhance student understanding. In the Technology Update to the Second Edition, we added Class Videos, Video Tutor Solutions, and Video Tutor Demonstrations. In the Third Edition, we added an exciting new supplement, **Prelecture Videos**, short videos with author Brian Jones that introduce the topics of each chapter with accompanying assessment questions. In the front of this book, you'll find an illustrated walkthrough of the new media available in this technology update for the third edition:

- **NEW! What the Physics? Videos** bring new, relatable content to engage students with what they are learning and promote curiosity for natural phenomena. These short videos present visually stimulating physical phenomena and pause throughout to address misconceptions and ask conceptual questions about the physics at hand. The videos are embedded in the eText as well as assignable in Mastering Physics. Quantitative questions are also available for assignment.
- **NEW! Direct Measurement Videos** are short videos that show real situations of physical phenomena. Grids, rulers, and frame counters appear as overlays, helping students to make precise measurements of quantities such as position and time. Students then apply these quantities along with physics concepts to solve problems and answer questions about the motion of the objects in the video. The problems are assignable in Mastering Physics and can be used to replace or supplement traditional word problems, or as open-ended questions to help develop problem-solving skills.
- **NEW! The Physics Primer** relies on videos, hints, and feedback to refresh students' math skills in the context of physics and prepares them for success in the course. These tutorials can be assigned before the course begins or throughout the course as just-in-time remediation. They ensure students practice and maintain their math skills, while tying together mathematical operations and physics analysis.
- **NEW! Quantitative Prelecture Videos** are assignable, interactive videos that complement the Conceptual Prelecture Videos, giving students exposure to concepts before class and helping them learn how problems for those concepts are worked.
- **NEW! Ready-to-Go Teaching Modules** provide instructors with easy-to-use tools for teaching the toughest topics in physics. These modules demonstrate how your colleagues effectively use all the resources Pearson has to offer to accompany *College Physics: A Strategic Approach*, including, but not limited to, Mastering Physics items. Ready-to-Go Teaching Modules were created for and by instructors to provide easy-to-use assignments for before, during, and after class. Assets also include in-class activities and questions in Learning Catalytics™.
- **Dynamic Study Modules (DSMs)** help students study on their own by continuously assessing their activity and performance in real time. Students complete a set of questions with a unique answer format that repeats each question until students can answer them all correctly and confidently.

- **Dynamic Figure Videos in each chapter** are one-minute videos based on figures from the textbook that depict important, but often challenging, physics principles.
- **Video Tutor Solutions** created by co-author Brian Jones are an engaging and helpful walkthrough of worked examples and select end-of-chapter (EOC) problems designed to help students solve problems for each main topic. Each chapter has seven Video Tutor Solutions.
- **Prep questions aligned with the MCAT exam** are based on the Foundational Concepts and Content Categories outlined by the Association of American Medical Colleges. These 140 new problems are assignable in Mastering Physics and available for self-study in the Study Area.
- **Video Tutor Demonstrations** feature “pause-and-predict” demonstrations of key physics concepts and incorporate assessment with answer-specific feedback.

Textbook Organization

College Physics: A Strategic Approach is divided into seven parts: Part I: *Force and Motion*, Part II: *Conservation Laws*, Part III: *Properties of Matter*, Part IV: *Oscillations and Waves*, Part V: *Optics*, Part VI: *Electricity and Magnetism*, and Part VII: *Modern Physics*.

Part I covers Newton’s laws and their applications. The coverage of two fundamental conserved quantities, momentum and energy, is in Part II, for two reasons. First, the way that problems are solved using conservation laws—comparing an *after* situation to a *before* situation—differs fundamentally from the problem-solving strategies used in Newtonian dynamics. Second, the concept of energy has a significance far beyond mechanical (kinetic and potential) energies. In particular, the key idea in thermodynamics is energy, and moving from the study of energy in Part II into thermal physics in Part III allows the uninterrupted development of this important idea.

Optics (Part V) is covered directly after oscillations and waves (Part IV), but *before* electricity and magnetism (Part VI). Further, we treat wave optics before ray optics. Our motivations for this organization are twofold. First, wave optics is largely just an extension of the general ideas of waves; in a more traditional organization, students will have forgotten much of what they learned about waves by the time they get to wave optics. Second, optics as it is presented in introductory physics makes no use of the properties of electromagnetic fields. The documented difficulties that students have with optics are difficulties with waves, not difficulties with electricity and magnetism. There’s little reason other than historical tradition to delay optics. However, the optics chapters are easily deferred until after Part VI for instructors who prefer that ordering of topics.

Preface to the Student

One may say the eternal mystery of the world is its comprehensibility.
—Albert Einstein

If you are taking a course for which this book is assigned, you probably aren't a physics major or an engineering major. It's likely that you aren't majoring in a physical science. So why are you taking physics?

It's almost certain that you are taking physics because you are majoring in a discipline that requires it. Someone, somewhere, has decided that it's important for you to take this course. And they are right. There is a lot you can learn from physics, even if you don't plan to be a physicist. We regularly hear from doctors, physical therapists, biologists, and others that physics was one of the most interesting and valuable courses they took in college.

So, what can you expect to learn in this course? Let's start by talking about what physics is. Physics is a way of thinking about the physical aspects of nature. Physics is not about "facts." It's far more focused on discovering *relationships* between facts and the *patterns* that exist in nature than on learning facts for their own sake. Our emphasis will be on thinking and reasoning. We are 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.



The concepts and techniques you will learn will have a wide application. In this text we have a special emphasis on applying physics to understanding the living world. You'll use your understanding of charges and electric potential to analyze the electrical signal produced when your heart beats. You'll

learn how sharks can detect this signal to locate prey and, further, how and why this electrical sensitivity seems to allow hammerhead sharks to detect magnetic fields, aiding navigation in the open ocean.

Like any subject, physics is best learned by doing. "Doing physics" in this course means solving problems, applying what you have learned to answer questions at the end of the chapter. When you are given a homework assignment, you may find yourself tempted to simply solve the problems by

thumbing through the text looking for a formula that seems like it will work. This isn't how to do physics; if it was, whoever required you to take this course wouldn't bother. The folks who designed your major want you to learn to *reason*, not to "plug and chug." Whatever you end up studying or doing for a career, this ability will serve you well.

How do you learn to reason in this way? There's no single strategy for studying physics that will work for all students, but we can make some suggestions that will certainly help:

- **Read each chapter *before* it is discussed in class.** Class attendance is much more effective if you have prepared.
- **Use the other resources that accompany the text.** The text includes many videos and online tools to help you better master new material.
- **Participate actively in class.** Take notes, ask and answer questions, take part in discussion groups. There is ample scientific evidence that *active participation* is far more effective for learning science than is passive listening.
- **After class, go back for a careful rereading of the chapter.** In your second reading, pay close attention to the details and the worked examples. Look for the *logic* behind each example, not just at what formula is being used.
- **Apply what you have learned to the homework problems at the end of each chapter.** By following the techniques of the worked examples, applying the tactics and problem-solving strategies, you'll learn how to apply the knowledge you are gaining.
- **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.
- **Don't be afraid to ask questions.** The more you engage with your instructor and other students, the more successful you will be.

We have one final suggestion. As you read the book, take part in class, and work through problems, step back every now and then to appreciate the big picture. You are going to study topics that range from motions in the solar system to the electrical signals in the nervous system that let you tell your hand to turn the pages of this book. It's a remarkable breadth of topics and techniques that is based on a very compact set of organizing principles.

Now, let's get down to work.

Correlation to the AP[®] Physics 1 and AP[®] Physics 2 Curriculum Framework

This chart correlates the College Board's Advanced Placement Physics Curriculum Framework (effective Fall 2017) to the corresponding chapters and sections in Knight/Jones/Field AP Edition of *College Physics: A Strategic Approach*, 4th Edition, AP Edition. For the most current correlation for this textbook, visit PearsonSchool.com/AdvancedCorrelations.

BIG IDEA 1 Objects and systems have properties such as mass and charge. Systems may have internal structure.

Enduring Understanding 1.A:	Chapter/Section
The internal structure of a system determines many properties of the system.	
1.A.1. A system is an object or a collection of objects. Objects are treated as having no internal structure.	2.6, 7.2, 7.4, 9.4, 20.3, 30.7
Phys. 1	
1.A.2. Fundamental particles have no internal structure.	28.3, 30.7
SP 1.1, 7.2	Phys. 2
1.A.3. Nuclei have internal structures that determine their properties.	29.2, 30.1, 30.2, 30.4, 30.5
Phys. 2	
1.A.4. Atoms have internal structures that determine their properties.	29.2–29.7
SP 1.1, 7.1	Phys. 2
1.A.5. Systems have properties determined by the properties and interactions of their constituent atomic and molecular substructures. In AP Physics, when the properties of the constituent parts are not important in modeling the behavior of the macroscopic system, the system itself may be referred to as an <i>object</i> .	11.3, 12.1, 12.2, 12.4, 12.5, 12.7, 12.8, 13.1
SP 1.1, 1.4, 7.1	Phys. 1, 2
Enduring Understanding 1.B:	
Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge.	
1.B.1. Electric charge is conserved. The net charge of a system is equal to the sum of the charges of all the objects in the system.	20.1, 20.2, 22.1, 22.2
SP 6.4, 7.2	Phys. 1, 2
1.B.2. There are only two kinds of electric charge. Neutral objects or systems contain equal quantities of positive and negative charge, with the exception of some fundamental particles that have no electric charge.	20.1–20.3, 30.1, 30.7
SP 6.1, 6.2, 6.4, 7.2	Phys. 1, 2
1.B.3. The smallest observed unit of charge that can be isolated is the electron charge, also known as the elementary charge.	20.1, 20.2, 29.2, 30.7
SP 1.5, 6.1, 7.2	Phys. 1, 2
Enduring Understanding 1.C:	
Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.	
1.C.1. Inertial mass is the property of an object or a system that determines how its motion changes when it interacts with other objects or systems.	4.5, 9.4–9.6
SP 4.2	Phys. 1
1.C.2. Gravitational mass is the property of an object or a system that determines the strength of the gravitational interaction with other objects, systems, or gravitational fields.	2.7, 6.5
Phys. 1	
1.C.3. Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.	6.5
SP 4.2	Phys. 1
1.C.4. In certain processes, mass can be converted to energy and energy can be converted to mass according to $E = mc^2$, the equation derived from the theory of special relativity.	27.10
SP 6.3	Phys. 2
Enduring Understanding 1.D:	
Classical mechanics cannot describe all properties of objects.	
1.D.1. Objects classically thought of as particles can exhibit properties of waves.	28.4
SP 6.3	Phys. 2

1.D.2. Certain phenomena classically thought of as waves can exhibit properties of particles.	28.2, 28.3, 28.6, 28.7
Phys. 2	
1.D.3. Properties of space and time cannot always be treated as absolute.	27.1, 27.5, 27.6, 27.10
SP 6.3, 7.1	Phys. 2
Enduring Understanding 1.E:	
Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.	
1.E.1. Matter has a property called density.	13.1, 13.3
SP 4.1, 4.2, 6.4	Phys. 2
1.E.2. Matter has a property called resistivity.	
SP 4.1	Phys. 1, 2
	22.4
1.E.3. Matter has a property called thermal conductivity.	12.8
SP 4.1, 4.2, 5.1	Phys. 2
1.E.4. Matter has a property called electric permittivity.	20.4, 21.7
	Phys. 2
1.E.5. Matter has a property called magnetic permeability.	24.4
	Phys. 2
1.E.6. Matter has a property called magnetic dipole moment.	24.8
	Phys. 2
BIG IDEA 2 Fields existing in space can be used to explain interactions.	
Enduring Understanding 2.A:	Chapter/Section
A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur at a distance (long-range forces) as well as a variety of other physical phenomena.	
2.A.1. A vector field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a vector.	20.4, 20.5
	Phys. 1, 2
2.A.2. A scalar field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a scalar. In Physics 2, this should include electric potential.	21.4, 21.5
	Phys. 2
Enduring Understanding 2.B:	
A gravitational field is caused by an object with mass.	
2.B.1. A gravitational field \vec{g} at the location of an object with mass m causes a gravitational force of magnitude mg to be exerted on the object in the direction of the field.	5.3, 6.5
SP 2.2, 7.2	Phys. 1
2.B.2. The gravitational field caused by a spherically symmetric object with mass is radial and, outside the object, varies as the inverse square of the radial distance from the center of that object.	6.5
SP 2.2	Phys. 1
Enduring Understanding 2.C:	
An electric field is caused by an object with electric charge.	
2.C.1. The magnitude of the electric force F exerted on an object with electric charge q by an electric field \vec{E} is $\vec{F} = q\vec{E}$. The direction of the force is determined by the direction of the field and the sign of the charge, with positively charged objects accelerating in the direction of the field and negatively charged objects accelerating in the direction opposite the field. This should include a vector field map for positive point charges, negative point charges, spherically symmetric charge distribution, and uniformly charged parallel plates.	20.4, 20.5
SP 2.2, 6.4, 7.2	Phys. 2
2.C.2. The magnitude of the electric field vector is proportional to the net electric charge of the object(s) creating that field. This includes positive point charges, negative point charges, spherically symmetric charge distributions, and uniformly charged parallel plates.	20.4, 20.5
SP 2.2, 6.4	Phys. 2
2.C.3. The electric field outside a spherically symmetric charged object is radial and its magnitude varies as the inverse square of the radial distance from the center of that object. Electric field lines are not in the curriculum. Students will be expected to rely only on the rough intuitive sense underlying field lines, wherein the field is viewed as analogous to something emanating uniformly from a source.	20.4
SP 6.2	Phys. 2
2.C.4. The electric field around dipoles and other systems of electrically charged objects (that can be modeled as point objects) is found by vector addition of the field of each individual object. Electric dipoles are treated qualitatively in this course as a teaching analogy to facilitate student understanding of magnetic dipoles.	20.5
SP 1.4, 2.2, 6.4, 7.2	Phys. 2

2.C.5. Between two oppositely charged parallel plates with uniformly distributed electric charge, at points far from the edges of the plates, the electric field is perpendicular to the plates and is constant in both magnitude and direction. SP 1.1, 2.2, 7.1	20.5 Phys. 2
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Enduring Understanding 2.D:

A magnetic field is caused by a magnet or a moving electrically charged object. Magnetic fields observed in nature always seem to be produced either by moving charged objects or by magnetic dipoles or combinations of dipoles and never by single poles.	
2.D.1. The magnetic field exerts a force on a moving electrically charged object. That magnetic force is perpendicular to the direction of velocity of the object and to the magnetic field and is proportional to the magnitude of the charge, the magnitude of the velocity and the magnitude of the magnetic field. It also depends on the angle between the velocity, and the magnetic field vectors. Treatment is quantitative for angles of 0°, 90°, or 180° and qualitative for other angles. SP 2.2	24.5 Phys. 2
2.D.2. The magnetic field vectors around a straight wire that carries electric current are tangent to concentric circles centered on that wire. The field has no component toward the current-carrying wire. SP 1.1	24.3, 24.4 Phys. 2
2.D.3. A magnetic dipole placed in a magnetic field, such as the ones created by a magnet or the Earth, will tend to align with the magnetic field vector. SP 1.2	24.7 Phys. 2
2.D.4. Ferromagnetic materials contain magnetic domains that are themselves magnets. SP 1.4	24.8 Phys. 2

Enduring Understanding 2.E:

Physicists often construct a map of isolines connecting points of equal value for some quantity related to a field and use these maps to help visualize the field.	
2.E.1. Isolines on a topographic (elevation) map describe lines of approximately equal gravitational potential energy per unit mass (gravitational equipotential). As the distance between two different isolines decreases, the steepness of the surface increases. [Contour lines on topographic maps are useful teaching tools for introducing the concept of equipotential lines. Students are encouraged to use the analogy in their answers when explaining gravitational and electrical potential and potential differences.] SP 1.4, 6.4, 7.2	21.4 Phys. 2
2.E.2. Isolines in a region where an electric field exists represent lines of equal electric potential, referred to as equipotential lines. SP 1.4, 6.4, 7.2	21.4 Phys. 2
2.E.3. The average value of the electric field in a region equals the change in electric potential across that region divided by the change in position (displacement) in the relevant direction. Phys. 2	21.5

BIG IDEA 3 The interactions of an object with other objects can be described by forces.

Enduring Understanding 3.A:

Chapter/Section

All forces share certain common characteristics when considered by observers in inertial reference frames.	
3.A.1. An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration. SP 1.5, 2.1, 2.2, 4.2, 5.1	1.3, 1.4, 1.6, 1.7, 2.1, 2.2, 2.4, 2.5, 3.2, 3.8, 27.2, 27.3 Phys. 1
3.A.2. Forces are described by vectors. SP 1.1	4.1, 4.4 Phys. 1, 2
3.A.3. A force exerted on an object is always due to the interaction of that object with another object. SP 1.4, 6.1, 6.4, 7.2	4.1, 4.2, 4.5, 5.1, 5.7, 6.2, 6.5, 9.2 Phys. 1, 2
3.A.4. If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction. SP 1.4, 6.2, 6.4, 7.2	4.7, 5.7, 6.5, 9.4 Phys. 1, 2

Enduring Understanding 3.B:

Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\sum \vec{F}}{m}$.

3.B.1. If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. SP 1.5, 2.2, 4.2, 5.1, 6.4, 7.2	4.6, 5.1–5.3, 5.8, 5.9, 6.1, 20.3 Phys. 1, 2
3.B.2. Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation. SP 1.1, 1.4, 2.2	4.1–4.3, 4.6, 4.7, 5.1, 5.3, 5.8, 5.9, 6.1 Phys. 1, 2

3.B.3. Restoring forces can result in oscillatory motion. When a linear restoring force is exerted on an object displaced from an equilibrium position, the object will undergo a special type of motion called simple harmonic motion. Examples should include gravitational force exerted by the Earth on a simple pendulum, mass-spring oscillator.	14.2–14.5
SP 2.2, 4.2, 5.1, 6.2, 6.4, 7.2	Phys. 1

Enduring Understanding 3.C:

At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.	
3.C.1. Gravitational force describes the interaction of one object that has mass with another object that has mass.	5.3, 6.5
SP 2.2	Phys. 1
3.C.2. Electric force results from the interaction of one object that has an electric charge with another object that has an electric charge.	20.1, 20.2, 20.3
SP 2.2, 6.4, 7.2	Phys. 1, 2
3.C.3. A magnetic force results from the interaction of a moving charged object or a magnet with other moving charged objects or another magnet.	24.1, 24.5, 24.7
SP 1.4, 4.2, 5.1	Phys. 2
3.C.4. Contact forces result from the interaction of one object touching another object and they arise from inter-atomic electric forces. These forces include tension, friction, normal, spring (Physics 1), and buoyant (Physics 2).	4.2, 4.7, 9.1, 9.2, 9.4, 14.2
SP 6.1, 6.2	Phys. 1, 2

Enduring Understanding 3.D:

A force exerted on an object can change the momentum of the object.	
3.D.1. The change in momentum of an object is a vector in the direction of the net force exerted on the object.	9.2, 9.4
SP 4.1	Phys. 1
3.D.2. The change in momentum of an object occurs over a time interval.	9.2, 9.4
SP 2.1, 4.2, 5.1, 6.4	Phys. 1

Enduring Understanding 3.E:

A force exerted on an object can change the kinetic energy of the object.	
3.E.1. The change in the kinetic energy of an object depends on the force exerted on the object and on the displacement of the object during the interval that the force is exerted.	10.2, 10.3, 10.4
SP 1.4, 2.2, 6.4, 7.2	Phys. 1

Enduring Understanding 3.F:

A force exerted on an object can cause a torque on that object.	
3.F.1. Only the force component perpendicular to the line connecting the axis of rotation and the point of application of the force results in a torque about that axis.	7.3, 8.1
SP 1.4, 2.2, 2.3, 4.1, 4.2, 5.1	Phys. 1
3.F.2. The presence of a net torque along any axis will cause a rigid system to change its rotational motion or an object to change its rotational motion about that axis.	7.1–7.3, 7.5–7.7
SP 4.1, 4.2, 5.1, 6.4	Phys. 1
3.F.3. A torque exerted on an object can change the angular momentum of an object.	9.7
SP 2.1, 4.1, 4.2, 5.1, 5.3, 6.4, 7.2	Phys. 1

Enduring Understanding 3.G:

Certain types of forces are considered fundamental.	
3.G.1. Gravitational forces are exerted at all scales and dominate at the largest distance and mass scales.	6.6
SP 7.1	Phys. 1, 2
3.G.2. Electromagnetic forces are exerted at all scales and can dominate at the human scale.	20.1, 20.2
SP 7.1	Phys. 2
3.G.3. The strong force is exerted at nuclear scales and dominates the interactions of nucleons.	30.3
SP 7.2	Phys. 2

BIG IDEA 4 Interactions between systems can result in changes in those systems.

Enduring Understanding 4.A:

Chapter/Section

The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\vec{a} = \frac{\sum \vec{F}}{m}$.	
4.A.1. The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass.	7.3
SP 1.2, 1.4, 2.3, 6.4	Phys. 1
4.A.2. The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time.	2.1–2.5, 4.1, 4.5, 9.4
SP 1.4, 2.2, 5.3, 6.4	Phys. 1

4.A.3. Forces that systems exert on each other are due to interactions between objects in the systems. If the interacting objects are parts of the same system, there will be no change in the center-of-mass velocity of that system. SP 1.4, 2.2	Phys. 1	9.4
Enduring Understanding 4.B:		
Interactions with other objects or systems can change the total linear momentum of a system.		
4.B.1. The change in linear momentum for a constant-mass system is the product of the mass of the system and the change in velocity of the center of mass. SP 1.4, 2.2, 5.1	Phys. 1	9.2
4.B.2. The change in linear momentum of the system is given by the product of the average force on that system and the time interval during which the force is exerted. SP 2.2, 5.1	Phys. 1	9.2–9.4
Enduring Understanding 4.C:		
Interactions with other objects or systems can change the total energy of a system.		
4.C.1. The energy of a system includes its kinetic energy, potential energy, and microscopic internal energy. Examples should include gravitational potential energy, elastic potential energy, and kinetic energy. SP 1.4, 2.1, 2.2, 6.4	Phys. 1	10.1–10.9, 21.1–21.4
4.C.2. Mechanical energy (the sum of kinetic and potential energy) is transferred into or out of a system when an external force is exerted on a system such that a component of the force is parallel to its displacement. The process through which the energy is transferred is called work. SP 1.4, 2.2, 6.4, 7.2	Phys. 1	10.1–10.3, 12.3
4.C.3. Energy is transferred spontaneously from a higher temperature system to a lower temperature system. The process through which energy is transferred between systems at different temperatures is called heat. SP 6.4	Phys. 2	12.5, 12.6, 12.8
4.C.4. Mass can be converted into energy and energy can be SP 2.2, 2.3, 7.2	Phys. 2	27.10, 30.2, 30.4
Enduring Understanding 4.D:		
A net torque exerted on a system by other objects or systems will change the angular momentum of the system.		
4.D.1. Torque, angular velocity, angular acceleration, and angular momentum are vectors and can be characterized as positive or negative depending upon whether they give rise to or correspond to counterclockwise or clockwise rotation with respect to an axis. SP 1.2, 1.4, 3.2, 4.1, 4.2, 5.1, 5.3	Phys. 1	7.2, 7.3, 8.1
4.D.2. The angular momentum of a system may change due to interactions with other objects or systems. SP 1.2, 1.4, 4.2	Phys. 1	9.7
4.D.3. The change in angular momentum is given by the product of the average torque and the time interval during which the torque is exerted. SP 2.2, 4.1, 4.2	Phys. 1	9.7
Enduring Understanding 4.E:		
The electric and magnetic properties of a system can change in response to the presence of, or changes in, other objects or systems.		
4.E.1. The magnetic properties of some materials can be affected by magnetic fields at the system. Students should focus on the underlying concepts and not the use of the vocabulary. SP 1.1, 1.4, 2.2	Phys. 2	24.8
4.E.2. Changing magnetic flux induces an electric field that can establish an induced emf in a system. SP 6.4	Phys. 2	25.1–25.4
4.E.3. The charge distribution in a system can be altered by the effects of electric forces produced by a charged object. SP 1.1, 1.4, 3.2, 4.1, 4.2, 5.1, 5.3, 6.4, 7.2	Phys. 2	20.1, 20.2, 22.1, 22.2
4.E.4. The resistance of a resistor, and the capacitance of a capacitor, can be understood from the basic properties of electric fields and forces, as well as the properties of materials and their geometry. SP 2.2, 4.1, 4.2, 5.1, 6.4	Phys. 2	20.5, 21.7, 22.4, 22.5, 22.6
4.E.5. The values of currents and electric potential differences in an electric circuit are determined by the properties and arrangement of the individual circuit elements such as sources of emf, resistors, and capacitors. SP 2.2, 4.2, 5.1, 6.1, 6.4	Phys. 2	23.1–23.7

BIG IDEA 5 Changes that occur as a result of interactions are constrained by conservation laws.

Enduring Understanding 5.A:	Chapter/Section
Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.	
5.A.1. A system is an object or a collection of objects. The objects are treated as having no internal structure. Phys. 1	9.4

5.A.2. For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings. SP 6.4, 7.2	Phys. 1	9.4–9.7, 10.1, 20.1, 20.2, 22.1, 22.2
Enduring Understanding 5.A:		
5.A.3. An interaction can be either a force exerted by objects outside the system or the transfer of some quantity with objects outside the system. Phys. 1	Phys. 1	9.1–9.3, 9.7, 10.1–10.3, 10.5, 10.6, 11.2, 11.3, 11.4, 14.6, 14.7, 20.1
5.A.4. The boundary between a system and its environment is a decision made by the person considering the situation in order to simplify or otherwise assist in analysis. Phys. 1	Phys. 1	9.4
Enduring Understanding 5.B:		
The energy of a system is conserved.		
5.B.1. Classically, an object can only have kinetic energy since potential energy requires an interaction between two or more objects. SP 1.4, 1.5, 2.2	Phys. 1	10.1, 10.3
5.B.2. A system with internal structure can have internal energy, and changes in a system's internal structure can result in changes in internal energy. [Physics 1: includes mass-spring oscillators and simple pendulums. Physics 2: includes charged object in electric fields and examining changes in internal energy with changes in configuration.] SP 1.4, 2.1	Phys. 1, 2	
5.B.3. A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces. SP 1.4, 2.2, 6.4, 7.2	Phys. 1	10.1, 10.2, 10.4, 21.1–21.3, 22.4–22.6
5.B.4. The internal energy of a system includes the kinetic energy of the objects that make up the system and the potential energy of the configuration of the objects that make up the system. SP 1.4, 2.1, 2.2, 6.4, 7.2	Phys. 1, 2	10.1, 10.3, 10.4, 10.7, 14.4
5.B.5. Energy can be transferred by an external force exerted on an object or system that moves the object or system through a distance; this energy transfer is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system. [A piston filled with gas getting compressed or expanded is treated in Physics 2 as a part of thermodynamics.] SP 1.4, 2.2, 4.2, 5.1, 6.4, 7.2	Phys. 1, 2	10.1–10.4, 10.10, 12.3, 22.6
5.B.6. Energy can be transferred by thermal processes involving differences in temperature; the amount of energy transferred in this process of transfer is called heat. SP 1.2	Phys. 2	11.1, 11.3, 12.5–12.8
5.B.7. The first law of thermodynamics is a specific case of the law of conservation of energy involving the internal energy of a system and the possible transfer of energy through work and/or heat. Examples should include P-V diagrams—iso volumetric process, isothermal process, isobaric process, adiabatic process. No calculations of heat or internal energy from temperature change; and in this course, examples of these relationships are qualitative and/or semi-quantitative. SP 1.1, 1.4, 2.2, 6.4, 7.2	Phys. 2	11.1, 11.3–11.6, 12.3
5.B.8. Energy transfer occurs when photons are absorbed or emitted, for example, by atoms or nuclei. SP 1.2, 7.2	Phys. 2	28.5, 28.6
5.B.9. Kirchhoff's loop rule describes conservation of energy in electrical circuits. The application of Kirchhoff's laws to circuits is introduced in Physics 1 and further developed in Physics 2 in the context of more complex circuits, including those with capacitors. SP 1.1, 1.4, 1.5, 2.1, 2.2, 4.1, 4.2, 5.1, 5.3, 6.4, 7.2	Phys. 1, 2	21.1, 21.2, 22.3, 22.4, 22.5, 22.6, 23.2–23.7
5.B.10. Bernoulli's equation describes the conservation of energy in fluid flow. SP 2.2, 6.2	Phys. 2	13.5
5.B.11. Beyond the classical approximation, mass is actually part of the internal energy of an object or system with $E = mc^2$. SP 2.2, 7.2	Phys. 2	27.10
Enduring Understanding 5.C:		
The electric charge of a system is conserved.		
5.C.1. Electric charge is conserved in nuclear and elementary particle reactions, even when elementary particles are produced or destroyed. Examples should include equations representing nuclear decay. SP 6.4, 7.2	Phys. 2	30.4, 30.7
5.C.2. The exchange of electric charges among a set of objects in a system conserves electric charge. SP 4.1, 4.2, 5.1, 6.4	Phys. 2	20.1, 20.2

5.C.3. Kirchhoff's junction rule describes the conservation of electric charge in electrical circuits. Since charge is conserved, current must be conserved at each junction in the circuit. Examples should include circuits that combine resistors in series and parallel. [Physics 1: covers circuits with resistors in series, with at most one parallel branch, one battery only. Physics 2: includes capacitors in steady-state situations. For circuits with capacitors, situations should be limited to open circuit, just after circuit is closed, and a long time after the circuit is closed.]	22.1, 22.2, 23.2, 23.6–23.8
SP 1.4, 2.2, 4.1, 4.2, 5.1, 6.4, 7.2	Phys. 1, 2

Enduring Understanding 5.D:

The linear momentum of a system is conserved.

5.D.1. In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after.	9.4, 10.9
SP 2.1, 2.2, 3.2, 4.2, 5.1, 5.3, 6.4, 7.2	Phys. 1, 2
5.D.2. In a collision between objects, linear momentum is conserved. In an inelastic collision, kinetic energy is not the same before and after the collision.	9.4–9.6, 10.9
SP 2.1, 2.2, 4.1, 4.2, 4.4, 5.1, 5.3, 6.4, 7.2	Phys. 1, 2
5.D.3. The velocity of the center of mass of the system cannot be changed by an interaction within the system. [Physics 1: includes no calculations of centers of mass; the equation is not provided until Physics 2. However, without doing calculations, Physics 1 students are expected to be able to locate the center of mass of highly symmetric mass distributions, such as a uniform rod or cube of uniform density, or two spheres of equal mass.]	7.3
SP 6.4	Phys. 1, 2

Enduring Understanding 5.E:

The angular momentum of a system is conserved.

5.E.1. If the net external torque exerted on the system is zero, the angular momentum of the system does not change.	9.7
SP 2.1, 2.2, 6.4, 7.2	Phys. 1
5.E.2. The angular momentum of a system is determined by the locations and velocities of the objects that make up the system. The rotational inertia of an object or system depends upon the distribution of mass within the object or system. Changes in the radius of a system or in the distribution of mass within the system result in changes in the system's rotational inertia, and hence in its angular velocity and linear speed for a given angular momentum. Examples should include elliptical orbits in an Earth-satellite system. Mathematical expressions for the moments of inertia will be provided where needed. Students will not be expected to know the parallel axis theorem.	9.7
SP 2.2	Phys. 1

Enduring Understanding 5.F:

Classically, the mass of a system is conserved.

5.F.1. The continuity equation describes conservation of mass flow rate in fluids. Examples should include volume rate of flow, mass flow rate.	13.4
SP 2.1, 2.2, 7.2	Phys. 2

Enduring Understanding 5.G:

Nucleon number is conserved.

5.G.1. The possible nuclear reactions are constrained by the law of conservation of nucleon number.	30.2, 30.4
SP 6.4	Phys. 2

BIG IDEA 6 Waves can transfer energy and momentum from one location to another without the permanent transfer of mass and serve as a mathematical model for the description of other phenomena.

Enduring Understanding 6.A:

Chapter/Section

A wave is a traveling disturbance that transfers energy and momentum.

6.A.1. Waves can propagate via different oscillation modes such as transverse and longitudinal.	15.1, 25.5
SP 1.2, 5.1, 6.2	Phys. 1, 2
6.A.2. For propagation, mechanical waves require a medium, while electromagnetic waves do not require a physical medium. Examples should include light traveling through a vacuum and sound not traveling through a vacuum.	15.1, 15.2, 15.4, 25.5
SP 6.4, 7.2	Phys. 1, 2
6.A.3. The amplitude is the maximum displacement of a wave from its equilibrium value.	15.3
SP 1.4	Phys. 1
6.A.4. Classically, the energy carried by a wave depends upon and increases with amplitude. Examples should include sound waves.	15.5, 15.6, 25.5
SP 6.4	Phys. 1

Enduring Understanding 6.B:

A periodic wave is one that repeats as a function of both time and position and can be described by its amplitude, frequency, wavelength, speed, and energy.

6.B.1. For a periodic wave, the period is the repeat time of the wave. The frequency is the number of repetitions of the wave per unit time. SP 1.4, 2.2	Phys. 1	15.3, 25.5
6.B.2. For a periodic wave, the wavelength is the repeat distance of the wave. SP 1.4	Phys. 1	15.3, 25.5
Enduring Understanding 6.B:		
6.B.3. A simple wave can be described by an equation involving one sine or cosine function involving the wavelength, amplitude, and frequency of the wave. SP 1.5	Phys. 2	15.3, 25.5
6.B.4. For a periodic wave, wavelength is the ratio of speed over frequency. SP 4.2, 5.1, 7.2	Phys. 1	15.3, 25.5
6.B.5. The observed frequency of a wave depends on the relative motion of source and observer. This is a qualitative treatment only. SP 1.4	Phys. 1	15.7
Enduring Understanding 6.C:		
Only waves exhibit interference and diffraction.		
6.C.1. When two waves cross, they travel through each other; they do not bounce off each other. Where the waves overlap, the resulting displacement can be determined by adding the displacements of the two waves. This is called superposition. SP 1.4, 6.4, 7.2	Phys. 2	16.1
6.C.2. When waves pass through an opening whose dimensions are comparable to the wavelength, a diffraction pattern can be observed. SP 1.4, 6.4, 7.2	Phys. 2	17.1, 17.5, 17.6, 28.1, 28.4
6.C.3. When waves pass through a set of openings whose spacing is comparable to the wavelength, an interference pattern can be observed. Examples should include monochromatic double-slit interference. SP 1.4, 6.4	Phys. 2	17.2–17.4
6.C.4. When waves pass by an edge, they can diffract into the “shadow region” behind the edge. Examples should include hearing around corners, but not seeing around them, and water waves bending around obstacles. SP 6.4, 7.2	Phys. 2	17.1
Enduring Understanding 6.D:		
Interference and superposition lead to standing waves and beats.		
6.D.1. Two or more wave pulses can interact in such a way as to produce amplitude variations in the resultant wave. When two pulses cross, they travel through each other; they do not bounce off each other. Where the pulses overlap, the resulting displacement can be determined by adding the displacements of the two pulses. This is called superposition. SP 1.1, 1.4, 4.2, 5.1	Phys. 1	16.1
6.D.2. Two or more traveling waves can interact in such a way as to produce amplitude variations in the resultant wave. SP 5.1	Phys. 1	16.7
6.D.3. Standing waves are the result of the addition of incident and reflected waves that are confined to a region and have nodes and antinodes. Examples should include waves on a fixed length of string, and sound waves in both closed and open tubes. SP 1.2, 2.1, 3.2, 4.1, 4.2, 5.1, 5.2, 5.3, 6.4	Phys. 1	16.2–16.4
6.D.4. The possible wavelengths of a standing wave are determined by the size of the region to which it is confined. SP 1.5, 2.2, 6.1	Phys. 1	16.2–16.4
6.D.5. Beats arise from the addition of waves of slightly different frequency. SP 1.2	Phys. 1	16.7
Enduring Understanding 6.E:		
The direction of propagation of a wave such as light may be changed when the wave encounters an interface between two media.		
6.E.1. When light travels from one medium to another, some of the light is transmitted, some is reflected, and some is absorbed. (Qualitative understanding only.) SP 6.4, 7.2	Phys. 2	18.1
6.E.2. When light hits a smooth reflecting surface at an angle, it reflects at the same angle on the other side of the line perpendicular to the surface (specular reflection); and this law of reflection accounts for the size and location of images seen in plane mirrors. SP 6.4, 7.2	Phys. 2	18.2
6.E.3. When light travels across a boundary from one transparent material to another, the speed of propagation changes. At a non-normal incident angle, the path of the light ray bends closer to the perpendicular in the optically slower substance. This is called refraction. SP 1.1, 1.4, 4.1, 5.1, 5.2, 5.3, 6.4, 7.2	Phys. 2	18.3

6.E.4. The reflection of light from surfaces can be used to form images. SP 1.4, 2.2, 3.2, 4.1, 5.1, 5.2, 5.3	Phys. 2	18.2
6.E.5. The refraction of light as it travels from one transparent medium to another can be used to form images. SP 1.4, 2.2, 3.2, 4.1, 5.1, 5.2, 5.3	Phys. 2	18.4, 18.5, 19.1–19.5

Enduring Understanding 6.F:

Electromagnetic radiation can be modeled as waves or as fundamental particles.

6.F.1. Types of electromagnetic radiation are characterized by their wavelengths, and certain ranges of wavelength have been given specific names. These include (in order of increasing wavelength spanning a range from picometers to kilometers) gamma rays, x-rays, ultraviolet, visible light, infrared, microwaves, and radio waves. SP 6.4, 7.2	Phys. 2	15.1, 15.4, 25.5
6.F.2. Electromagnetic waves can transmit energy through a medium and through a vacuum. SP 1.1	Phys. 2	15.1, 15.4, 25.5
6.F.3. Photons are individual energy packets of electromagnetic waves, with $E_{\text{photon}} = hf$, where h is Planck's constant and f is the frequency of the associated light wave. SP 6.4	Phys. 2	28.2, 28.3, 28.6
6.F.4. The nature of light requires that different models of light are most appropriate at different scales. SP 6.4, 7.1	Phys. 2	28.3

Enduring Understanding 6.G:

All matter can be modeled as waves or as particles.

6.G.1. Under certain regimes of energy or distance, matter can be modeled as a classical particle. SP 6.4, 7.1	Phys. 2	28.4
6.G.2. Under certain regimes of energy or distance, matter can be modeled as a wave. The behavior in these regimes is described by quantum mechanics. SP 6.1, 6.4	Phys. 2	28.4

BIG IDEA 7 The mathematics of probability can be used to describe the behavior of complex systems and to interpret the behavior of quantum mechanical systems.

Enduring Understanding 7.A:

Chapter/Section

The properties of an ideal gas can be explained in terms of a small number of macroscopic variables including temperature and pressure.

7.A.1. The pressure of a system determines the force that the system exerts on the walls of its container and is a measure of the average change in the momentum or impulse of the molecules colliding with the walls of the container. The pressure also exists inside the system itself, not just at the walls of the container. SP 1.4, 2.2, 6.4, 7.2	Phys. 2	12.2
7.A.2. The temperature of a system characterizes the average kinetic energy of its molecules. SP 7.1	Phys. 2	11.3, 12.2
7.A.3. In an ideal gas, the macroscopic (average) pressure (P), temperature (T), and volume (V), are related by the equation $PV = nKT$. SP 3.2, 4.2, 5.1, 6.4, 7.2	Phys. 2	12.2, 12.3

Enduring Understanding 7.B:

The tendency of isolated systems to move toward states with higher disorder is described by probability.

7.B.1. The approach to thermal equilibrium is a probability process. SP 6.2	Phys. 2	11.3, 11.4, 12.5, 12.8
7.B.2. The second law of thermodynamics describes the change in entropy for reversible and irreversible processes. Only a qualitative treatment is considered in this course. SP 7.1	Phys. 2	11.7

Enduring Understanding 7.C:

At the quantum scale, matter is described by a wave function, which leads to a probabilistic description of the microscopic world.

7.C.1. The probabilistic description of matter is modeled by a wave function, which can be assigned to an object and used to describe its motion and interactions. The absolute value of the wave function is related to the probability of finding a particle in some spatial region. (Qualitative treatment only, using graphical analysis.) SP 1.4	Phys. 2	28.4
7.C.2. The allowed states for an electron in an atom can be calculated from the wave model of an electron. SP 1.4	Phys. 2	28.4–28.6
7.C.3. The spontaneous radioactive decay of an individual nucleus is described by probability. SP 6.4	Phys. 2	30.1, 30.4, 30.5
7.C.4. Photon emission and absorption processes are described by probability. SP 1.1, 1.2	Phys. 2	28.6, 29.3, 29.4, 29.7, 29.9

Detailed Contents

Preface to the Instructor	iv
Preface to the Student	viii
Correlation to the College Board's AP [®] Physics 1 and AP Physics 2 Curriculum Framework	ix
Real-World Applications	xxiii

3.6 Projectile Motion: Solving Problems	87
3.7 Circular Motion	90
3.8 Relative Motion	93
SUMMARY	96
QUESTIONS AND PROBLEMS	97

PART I Force and Motion

OVERVIEW The Science of Physics	3
--	---

Chapter 1 Representing Motion 4

1.1 Motion: A First Look	5
1.2 Models and Modeling	7
1.3 Position and Time: Putting Numbers on Nature	8
1.4 Velocity	11
1.5 A Sense of Scale: Significant Figures, Scientific Notation, and Units	13
1.6 Vectors and Motion: A First Look	19
1.7 Where Do We Go from Here?	23
SUMMARY	25
QUESTIONS AND PROBLEMS	26

Chapter 2 Motion in One Dimension 32

2.1 Describing Motion	33
2.2 Uniform Motion	37
2.3 Instantaneous Velocity	41
2.4 Acceleration	44
2.5 Motion with Constant Acceleration	47
2.6 Solving One-Dimensional Motion Problems	51
2.7 Free Fall	55
SUMMARY	61
QUESTIONS AND PROBLEMS	62

Chapter 3 Vectors and Motion in Two Dimensions 71

3.1 Using Vectors	72
3.2 Coordinate Systems and Vector Components	74
3.3 Motion on a Ramp	79
3.4 Motion in Two Dimensions	82
3.5 Projectile Motion	85

Chapter 4 Forces and Newton's Laws of Motion 105

4.1 Motion and Forces	106
4.2 A Short Catalog of Forces	109
4.3 Identifying Forces	113
4.4 What Do Forces Do?	115
4.5 Newton's Second Law	117
4.6 Free-Body Diagrams	120
4.7 Newton's Third Law	122
SUMMARY	126
QUESTIONS AND PROBLEMS	127

Chapter 5 Applying Newton's Laws 134

5.1 Equilibrium	135
5.2 Dynamics and Newton's Second Law	138
5.3 Mass and Weight	141
5.4 Normal Forces	144
5.5 Friction	146
5.6 Drag	151
5.7 Interacting Objects	157
5.8 Ropes and Pulleys	159
SUMMARY	165
QUESTIONS AND PROBLEMS	166

Chapter 6 Circular Motion, Orbits, and Gravity 175

6.1 Uniform Circular Motion	176
6.2 Dynamics of Uniform Circular Motion	178
6.3 Apparent Forces in Circular Motion	184
6.4 Circular Orbits and Weightlessness	187
6.5 Newton's Law of Gravity	190
6.6 Gravity and Orbits	193
SUMMARY	197
QUESTIONS AND PROBLEMS	198

Chapter 7	Rotational Motion	205	10.3	Kinetic Energy	318
7.1	Describing Circular and Rotational Motion	206	10.4	Potential Energy	321
7.2	The Rotation of a Rigid Body	211	10.5	Thermal Energy	325
7.3	Torque	215	10.6	Conservation of Energy	327
7.4	Gravitational Torque and the Center of Gravity	219	10.7	Energy Diagrams	331
7.5	Rotational Dynamics and Moment of Inertia	223	10.8	Molecular Bonds and Chemical Energy	335
7.6	Using Newton's Second Law for Rotation	227	10.9	Energy in Collisions	339
7.7	Rolling Motion	231	10.10	Power	341
	SUMMARY	234		SUMMARY	345
	QUESTIONS AND PROBLEMS	235		QUESTIONS AND PROBLEMS	346
Chapter 8	Equilibrium And Elasticity	244	Chapter 11	Using Energy	354
8.1	Torque and Static Equilibrium	245	11.1	Transforming Energy	355
8.2	Stability and Balance	250	11.2	Energy in the Body	358
8.3	Springs and Hooke's Law	252	11.3	Temperature, Thermal Energy, and Heat	364
8.4	Stretching and Compressing Materials	255	11.4	The First Law of Thermodynamics	367
8.5	Forces and Torques in the Body	258	11.5	Heat Engines	369
	SUMMARY	263	11.6	Heat Pumps	372
	QUESTIONS AND PROBLEMS	264	11.7	Entropy and the Second Law of Thermodynamics	374
PART I SUMMARY	Force and Motion	272	11.8	Systems, Energy, and Entropy	377
ONE STEP BEYOND	Dark Matter and the Structure of the Universe	273		SUMMARY	382
PART I PROBLEMS		274		QUESTIONS AND PROBLEMS	383
PART II	Conservation Laws		PART II SUMMARY	Conservation Laws	390
OVERVIEW	Why Some Things Stay the Same	277	ONE STEP BEYOND	Order Out of Chaos	391
Chapter 9	Momentum	278	PART II PROBLEMS		392
9.1	Impulse	279	PART III	Properties of Matter	
9.2	Momentum and the Impulse-Momentum Theorem	280	OVERVIEW	Beyond the Particle Model	395
9.3	Solving Impulse and Momentum Problems	285	Chapter 12	Thermal Properties of Matter	396
9.4	Conservation of Momentum	287	12.1	The Atomic Model of Matter	397
9.5	Inelastic Collisions	292	12.2	The Atomic Model of an Ideal Gas	399
9.6	Momentum and Collisions in Two Dimensions	294	12.3	Ideal-Gas Processes	406
9.7	Angular Momentum	295	12.4	Thermal Expansion	412
	SUMMARY	300	12.5	Specific Heat and Heat of Transformation	414
	QUESTIONS AND PROBLEMS	301	12.6	Calorimetry	418
Chapter 10	Energy and Work	309	12.7	Specific Heats of Gases	421
10.1	The Basic Energy Model	310	12.8	Heat Transfer	422
10.2	Work	314	12.9	Diffusion	426
				SUMMARY	431
				QUESTIONS AND PROBLEMS	432

Chapter 13	Fluids	441	16.6	The Interference of Waves from Two Sources	565
13.1	Fluids and Density	442	16.7	Beats	569
13.2	Pressure	443	SUMMARY		572
13.3	Buoyancy	448	QUESTIONS AND PROBLEMS		573
13.4	Fluids in Motion	454	PART IV SUMMARY	Oscillations and Waves	580
13.5	Fluid Dynamics	457	ONE STEP BEYOND	Waves in the Earth and the Ocean	581
13.6	Viscosity and Poiseuille's Equation	461	PART IV PROBLEMS		582
13.7	The Circulatory System	463			
SUMMARY		470			
QUESTIONS AND PROBLEMS		471			
PART III SUMMARY	Properties of Matter	478	PART V	Optics	
ONE STEP BEYOND	Size and Life	479	OVERVIEW	Light Is a Wave	585
PART III PROBLEMS		480			
PART IV	Oscillations and Waves		Chapter 17	Wave Optics	586
OVERVIEW	Motion That Repeats Again and Again	483	17.1	What Is Light?	587
Chapter 14	OSCILLATIONS	484	17.2	The Interference of Light	590
14.1	Equilibrium and Oscillation	485	17.3	The Diffraction Grating	594
14.2	Linear Restoring Forces and SHM	487	17.4	Thin-Film Interference	599
14.3	Describing Simple Harmonic Motion	489	17.5	Single-Slit Diffraction	605
14.4	Energy in Simple Harmonic Motion	494	17.6	Circular-Aperture Diffraction	609
14.5	Pendulum Motion	499	SUMMARY		612
14.6	Damped Oscillations	502	QUESTIONS AND PROBLEMS		613
14.7	Driven Oscillations and Resonance	504	Chapter 18	Ray Optics	620
SUMMARY		509	18.1	The Ray Model of Light	621
QUESTIONS AND PROBLEMS		510	18.2	Reflection	624
Chapter 15	Traveling Waves and Sound	518	18.3	Refraction	627
15.1	The Wave Model	519	18.4	Image Formation by Refraction	631
15.2	Traveling Waves	520	18.5	Thin Lenses: Ray Tracing	633
15.3	Graphical and Mathematical Descriptions of Waves	524	18.6	Image Formation with Spherical Mirrors	639
15.4	Sound and Light Waves	529	18.7	The Thin-Lens Equation	644
15.5	Energy and Intensity	531	SUMMARY		649
15.6	Loudness of Sound	533	QUESTIONS AND PROBLEMS		650
15.7	The Doppler Effect and Shock Waves	536	Chapter 19	Optical Instruments	657
SUMMARY		541	19.1	The Camera	658
QUESTIONS AND PROBLEMS		542	19.2	The Human Eye	660
Chapter 16	Superposition and Standing Waves	549	19.3	The Magnifier	667
16.1	The Principle of Superposition	550	19.4	The Microscope	670
16.2	Standing Waves	551	19.5	The Telescope	673
16.3	Standing Waves on a String	553	19.6	Color and Dispersion	674
16.4	Standing Sound Waves	558	19.7	Resolution of Optical Instruments	677
16.5	Speech and Hearing	563	SUMMARY		683
			QUESTIONS AND PROBLEMS		684
			PART V SUMMARY	Optics	690
			ONE STEP BEYOND	Scanning Confocal Microscopy	691
			PART V PROBLEMS		692

PART VI Electricity and Magnetism

OVERVIEW	Charges, Currents, and Fields	695
-----------------	-------------------------------	-----

Chapter 20 Electric Fields and Forces 696

20.1	Charges and Forces	697
20.2	Charges, Atoms, and Molecules	703
20.3	Coulomb's Law	705
20.4	The Concept of the Electric Field	710
20.5	The Electric Field of Multiple Charges	713
20.6	Conductors and Electric Fields	719
20.7	Forces and Torques in Electric Fields	721
	SUMMARY	725
	QUESTIONS AND PROBLEMS	726

Chapter 21 Electric Potential 734

21.1	Electric Potential Energy and Electric Potential	735
21.2	Sources of Electric Potential	737
21.3	Electric Potential and Conservation of Energy	740
21.4	Calculating the Electric Potential	743
21.5	Connecting Potential and Field	751
21.6	The Electrocardiogram	755
21.7	Capacitance and Capacitors	757
21.8	Energy and Capacitors	761
	SUMMARY	765
	QUESTIONS AND PROBLEMS	766

Chapter 22 Current and Resistance 774

22.1	A Model of Current	775
22.2	Defining and Describing Current	777
22.3	Batteries and emf	779
22.4	Connecting Potential and Current	780
22.5	Ohm's Law and Resistor Circuits	784
22.6	Energy and Power	788
	SUMMARY	792
	QUESTIONS AND PROBLEMS	793

Chapter 23 Circuits 800

23.1	Circuit Elements and Diagrams	801
23.2	Kirchhoff's Laws	802
23.3	Series and Parallel Circuits	805
23.4	Measuring Voltage and Current	810
23.5	More Complex Circuits	811
23.6	Capacitors in Parallel and Series	814
23.7	RC Circuits	816
23.8	Electricity in the Nervous System	819
	SUMMARY	827
	QUESTIONS AND PROBLEMS	828

Chapter 24 Magnetic Fields and Forces 838

24.1	Magnetism	839
24.2	The Magnetic Field	840
24.3	Electric Currents Also Create Magnetic Fields	844
24.4	Calculating the Magnetic Field Due to a Current	847
24.5	Magnetic Fields Exert Forces on Moving Charges	851
24.6	Magnetic Fields Exert Forces on Currents	858
24.7	Magnetic Fields Exert Torques on Dipoles	861
24.8	Magnets and Magnetic Materials	865
	SUMMARY	869
	QUESTIONS AND PROBLEMS	870

Chapter 25 EM Induction and EM Waves 879

25.1	Induced Currents	880
25.2	Motional emf	881
25.3	Magnetic Flux and Lenz's Law	884
25.4	Faraday's Law	889
25.5	Electromagnetic Waves	893
25.6	The Photon Model of Electromagnetic Waves	899
25.7	The Electromagnetic Spectrum	900
	SUMMARY	906
	QUESTIONS AND PROBLEMS	907

Chapter 26 AC Electricity 916

26.1	Alternating Current	917
26.2	AC Electricity and Transformers	919
26.3	Household Electricity	923
26.4	Biological Effects and Electrical Safety	925
26.5	Capacitor Circuits	927
26.6	Inductors and Inductor Circuits	929
26.7	Oscillation Circuits	932
	SUMMARY	937
	QUESTIONS AND PROBLEMS	938

PART VI SUMMARY Electricity and Magnetism 944**ONE STEP BEYOND The Greenhouse Effect and Global Warming 945****PART VI PROBLEMS 946**

PART VII Modern Physics**OVERVIEW** New Ways of Looking at the World 949**Chapter 27 Relativity 950**

27.1	Relativity: What's It All About?	951
27.2	Galilean Relativity	951
27.3	Einstein's Principle of Relativity	954
27.4	Events and Measurements	957
27.5	The Relativity of Simultaneity	960
27.6	Time Dilation	962
27.7	Length Contraction	968
27.8	Velocities of Objects in Special Relativity	970
27.9	Relativistic Momentum	971
27.10	Relativistic Energy	973
	SUMMARY	978
	QUESTIONS AND PROBLEMS	979

Chapter 28 Quantum Physics 986

28.1	X Rays and X-Ray Diffraction	987
28.2	The Photoelectric Effect	989
28.3	Photons	995
28.4	Matter Waves	997
28.5	Energy Is Quantized	1000
28.6	Energy Levels and Quantum Jumps	1002
28.7	The Uncertainty Principle	1005
28.8	Applications and Implications of Quantum Theory	1007
	SUMMARY	1010
	QUESTIONS AND PROBLEMS	1011

Chapter 29 Atoms and Molecules 1019

29.1	Spectroscopy	1020
29.2	Atoms	1022
29.3	Bohr's Model of Atomic Quantization	1025

29.4	The Bohr Hydrogen Atom	1027
29.5	The Quantum-Mechanical Hydrogen Atom	1032
29.6	Multi-electron Atoms	1034
29.7	Excited States and Spectra	1037
29.8	Molecules	1041
29.9	Stimulated Emission and Lasers	1042
	SUMMARY	1046
	QUESTIONS AND PROBLEMS	1047

Chapter 30 Nuclear Physics 1054

30.1	Nuclear Structure	1055
30.2	Nuclear Stability	1057
30.3	Forces and Energy in the Nucleus	1060
30.4	Radiation and Radioactivity	1062
30.5	Nuclear Decay and Half-Lives	1068
30.6	Medical Applications of Nuclear Physics	1073
30.7	The Ultimate Building Blocks of Matter	1079
	SUMMARY	1083
	QUESTIONS AND PROBLEMS	1084

PART VII SUMMARY Modern Physics 1090**ONE STEP BEYOND** The Physics of Very Cold Atoms 1091**PART VII PROBLEMS** 1092**Appendix A** Mathematics Review A-1**Appendix B** Periodic Table of Elements A-3**Appendix C** Atomic and Nuclear Data A-4**Answers** to Odd-Numbered Problems A-7**Credits** C-1**Index** I-1

Real-World Applications

Applications of biological or medical interest are marked **BIO** in the list below, including MCAT-style Passage Problems. Other end-of-chapter problems of biological or medical interest are marked **BIO** in the chapter.

Chapter 1

- Depth gauges 8
- Accuracy of long jumps 14
- Mars Climate Orbiter: unit error 16
- BIO** Navigating geese 24

Chapter 2

- Crash cushions 44
- BIO** Animal acceleration 44
- Rocket launch 47–48, 53
- BIO** Swan’s takeoff 50
- BIO** Chameleon tongues 52
- Runway design 54
- Braking distance 55
- BIO** A springbok’s pronk 58
- BIO** Cheetah vs. gazelle 60

Chapter 3

- Designing speed-ski slopes 80
- Dock jumping 87
- London Eye Ferris wheel 90
- Optimizing javelin throws 93
- BIO** Albatross’s speed 93
- BIO** Record-breaking frog jumps 95

Chapter 4

- BIO** Snake-necked turtle attack 105, 124
- Voyager and Newton’s first law 106
- Seatbelts and Newton’s first law 107
- Prosthetics for athletes 110
- BIO** Scallop propulsion 113
- Feel the difference (inertia) 117
- Race-car driver mass 118
- Bullets and Newton’s third law 123
- Rocket propulsion 124
- A mountain railway 125
- Pulling a stuck car from the mud 133

Chapter 5

- BIO** Gliding sifaka 125, 154
- Human tower 135
- Jumping on the moon 141
- Jumping in an elevator 142
- Weightless astronauts 144
- Antilock brakes 148
- BIO** Penguin drag coefficient 153
- Skydiver terminal speed 153–154
- BIO** Mass of a pollen grain 155
- BIO** *Paramecium* stopping distance 156
- BIO** Traction 161
- Stopping distances 164

Chapter 6

- Scottish heavy hammer throw 178
- BIO** Runner on a circular track 180–181
- Car cornering speed 181–182
- Wings on Indy racers 182
- Banked racetrack turns 183
- BIO** Maximum walking speed 168
- BIO** How you sense “up” 185
- Fast-spinning planets 186
- BIO** Centrifuges 186–187
- BIO** Human centrifuge 187
- BIO** Rotating space stations 189
- Variable gravity 192
- BIO** Walking on the moon 193
- Hunting with a sling 195–196

Chapter 7

- Clockwise clocks 211
- Starting a bike 216
- Designing wheelchair hand-rims 216
- Turning a capstan 218
- Granite ball and inertia 224
- Golf putter moment of inertia 225
- Balancing on a high wire 226
- Rolling vs. sliding: ancient movers 231
- Spinning a gyroscope 232–233
- BIO** Bunchberry petal release 242

Chapter 8

- BIO** Human stability and balance 244, 251
- BIO** Muscle forces 245
- BIO** Finding the body’s center of gravity 249
- Rollover safety for cars 250
- Ladder safety 251
- Balancing soda can 251
- Elasticity of a golf ball 252
- Running shoes and springs 253
- BIO** Bone strength 257–258
- BIO** Forces in the ankle joint 259–260
- BIO** Forces and torque in the elbow 260–261
- BIO** Carrying a heavy appliance 261
- Elevator cable stretch 262
- BIO** Elasticity of a Ligament

Part I Summary

- Dark matter 276
- BIO** Animal athletes 277

- BIO** Drag on a paramecium 277
- BIO** Diving falcon 278
- Bending beams 278

Chapter 9

- BIO** Ram skull adaptations 278, 284
- BIO** Optimizing frog jumps 281
- Stretchy seatbelts 284
- BIO** Hedgehog spines 284
- BIO** Birds taking flight 286–287
- BIO** Squid propulsion 292
- Colliding billiard balls 288
- Ice-skating spins 297
- Hurricanes 298
- Free-falling geckos 298
- Acrobatic bats 298
- Aerial firefighting 299
- BIO** Analyzing a dance move 308

Chapter 10

- Energy around us 318–319
- Flywheel energy storage on the ISS 328
- Why racing bike wheels are light 328–329
- Empire State Building race 330–331
- BIO** Energy storage in the Achilles tendon 332
- BIO** Jumping locusts 336–337
- Summet Plummet water slide speed 337
- Runaway-truck ramps 352

Chapter 11

- BIO** Kangaroo locomotion 354, 390
- Lightbulb efficiency 357
- BIO** Biochemical efficiency 358
- BIO** Energy in the body: inputs 358–359
- BIO** Calorie content of foods 359
- BIO** Energy in the body: outputs 359–360
- BIO** Daily energy use for mammals and reptiles 361
- BIO** Energy and locomotion 363
- Optical molasses 365
- Heat engines 370
- Reversible heat pump 373
- BIO** Entropy in biological systems 378–379
- Efficiency of an automobile 380–381
- BIO** Animal power 389

Part II Summary

- Order out of chaos 391
- BIO Squid propulsion 393
- Golf club collisions 393

Chapter 12

- BIO Infrared images 396, 426, 431
- Temperature in space 400
- Frost on Mars 401
- BIO Swim-bladder damage to caught fish 403
- Tire gauges 404
- Elevation and bag expansion 408
- Chinook winds 411
- Thermal expansion joints 412
- Temperate lakes 414
- BIO Frogs that survive freezing 416
- BIO Keeping cool 418
- Sweating glass 418
- BIO Penguin feet 424
- BIO Penguin feathers 424
- Heat transfer on earth 425
- BIO Hellbender respiration 429
- BIO Photosynthesis and carbon dioxide diffusion 429
- BIO Breathing in cold air 430
- Ocean temperature 440
- BIO The work of breathing 440

Chapter 13

- BIO Albatross and Bernoulli effect, 441, 458
- Submarine windows 445
- Pressure zones on weather maps 447
- Barometers 447
- Floating icebergs and boats 451
- Hot-air balloons 452–453
- Manatees: masters of density 453
- Airplane lift 458
- BIO Prairie dog burrows 459
- BIO Measuring arterial pressure 460
- BIO Measuring blood pressure 463
- BIO Blood pressure in giraffes 465
- BIO Blood pressure and flow 465–466, 477
- BIO Capillaries and diffusion 466
- BIO Horse hooves and circulation 468
- BIO Intravenous transfusions 468–469

Part III Summary

- BIO Scales of living creatures 479
- BIO Perspiration 480
- Weather balloons 480
- Passenger balloons 481

Chapter 14

- BIO Gibbon brachiation 484, 502
- BIO Heart rhythms 485
- BIO Simple harmonic motion 486
- Metronomes 490
- Microwaves and SHM 493

- Swaying buildings 493
- Measuring mass in space 496
- BIO Weighing DNA 497–498
- Car collision times 499
- BIO Animal locomotion 502
- Shock absorbers 503
- Tidal resonance 504
- Musical glasses 505
- BIO Hearing (resonance) 506
- Springboard diving 507–508
- BIO Achilles tendon as a spring 517
- BIO Spider-web oscillations 517

Chapter 15

- BIO Echolocation 518, 529, 548
- “The Wave” 519
- BIO Frog wave-sensors 521
- BIO Spider vibration sense 522
- Distance to a lightning strike 523
- BIO Range of hearing 529
- BIO Ultrasound imaging 530
- BIO Owl ears 533
- BIO Blue whale vocalization 534
- BIO Hearing (cochlea hairs) 535
- Solar surface waves 536
- Red shifts in astronomy 538
- BIO Wildlife tracking with weather radar 538
- BIO Doppler blood flow meter 539
- Earthquake waves 540

Chapter 16

- Digderidoos 549, 558, 564
- Windows and transmitting light 554
- The Tacoma bridge standing wave 557
- String musical instruments 557
- Microwave cold spots 558
- Fiery sound waves 560
- BIO Resonances of the ear canal 561–562
- Wind musical instruments 562
- BIO Speech and hearing 563–565
- BIO Vowels and formants 564
- Saying “ah” 565
- BIO High-frequency hearing loss 565
- Active noise reduction 565
- Controlling exhaust noise 569
- BIO The bat detector 570
- BIO Dogs’ growls 571
- Harmonics and harmony 579

Part IV Summary

- Tsunamis 581
- Deep-water waves 582
- BIO Attenuation of ultrasound 582
- Measuring speed of sound 583

Chapter 17

- BIO Iridescent feathers 586, 603
- DVD colors 597

- Antireflection coatings 601
- Colors of soap bubbles and oil slicks 603

- BIO Peacock fern and structural color 603–604
- BIO Bluebirds and blue skies 605
- Breakwaters and Huygens’ principle 606
- Laser range finding 611
- BIO The Blue Morpho Butterfly 619

Chapter 18

- Glass repair and index of refraction 628
- Binoculars 630
- Snell’s window 630
- Optical fibers 631
- BIO Arthroscopic surgery 631
- BIO Water droplet as converging lens 638
- BIO Mirrored eyes (*Gigantocypris*) 641
- Supermarket mirrors 643
- BIO Optical fiber imaging 647–648
- Mirages 656

Chapter 19

- BIO The Anableps “four-eyed” fish 657, 667
- BIO A Nautilus eye 658
- Cameras 658–660
- BIO The human eye 660–667
- Prescription lenses 660
- BIO Eye’s range of accommodation, 663
- BIO Vision correction 664, 665–667
- BIO Penguin eyes 667
- Forced perspective in movies 668
- BIO Microscopes 670–673, 681
- Telescopes above the atmosphere 673
- Rainbows 676
- BIO Absorption of chlorophyll 677
- Fixing the HST 678
- BIO Optical and electron micrographs 680
- BIO Visual acuity for a kestrel 682
- BIO The blind spot 685
- BIO Surgical vision correction 689

Part V Summary

- BIO Scanning confocal microscopy 691
- BIO Horse vision 692
- BIO Eye shine 692–693
- BIO Pupil size 693

Chapter 20

- BIO Bee navigation 696, 711
- Amber attraction 697
- Dust in the wind 699
- Static electricity on a slide 700
- BIO Bees picking up pollen 702
- BIO Hydrogen bonds in DNA 705

- BIO** Separating sperm cells 706
- Electrostatic precipitators 715–716
- BIO** Electric field of the heart 718
- Static protection 720
- Lightning rods 720
- BIO** Electrolocation 720
- Cathode-ray tubes 723–724
- BIO** Flow cytometry 733

Chapter 21

- BIO** Rays and electric potential 734, 757
- Cause of lightning 738, 773
- BIO** Membrane potential 739
- BIO** Proton therapy 743
- BIO** Bumblebee electric-field sensitivity 749
- Airplanes and lightning strikes 754
- BIO** The electrocardiogram 755–756
- BIO** Shark electroreceptors 757
- Random-access memory 759
- BIO** Plant roots and capacitance 761
- Camera flashes 761
- BIO** Defibrillators 762
- Fusion in the sun 764

Chapter 22

- BIO** Percentage body-fat measurement 774, 790–791
- BIO** The electric torpedo ray 780
- Lightbulb filaments 783
- Testing drinking water 784
- BIO** Impedance tomography 784
- Photoresistor night lights 785
- Cooking hot dogs with electricity 788
- Monitoring corrosion in power lines 789
- Lightbulb failure 799

Chapter 23

- BIO** Electric fish 800, 837
- Christmas-tree lights 807
- Headlight wiring 809
- Thermistors in measuring devices 811
- Cell phone circuitry, 812
- Flashing bike light 816
- Intermittent windshield wipers 819
- BIO** Electricity in the nervous system 819–825
- BIO** Electrical nature of nerve and muscle cells 819
- BIO** Interpreting brain electric potentials 822
- Soil moisture measurement 826
- BIO** Cardiac defibrillators 837

Chapter 24

- BIO** Magnetic resonance imaging 838, 850, 864

- BIO** Magnetotactic bacteria 843
- BIO** Magnetocardiograms 849
- Digital compass 853
- The aurora 855
- BIO** Cyclotrons 856
- BIO** Electromagnetic flowmeters 857
- Electric motors 864
- Hard disk data storage 867
- Rotating magnetic bacteria 868
- The velocity selector 877
- Ocean potentials 878
- The mass spectrometer 878

Chapter 25

- BIO** Color vision in animals 879, 903
- BIO** Shark navigation 882
- Generators 883–884
- Wind turbine 884
- Electric guitar pickups 889
- Magnetic braking 892
- BIO** Transcranial magnetic stimulation 892
- Radio transmission 894
- Solar tower of power 895
- Polarizers 896–898
- BIO** Polarizers and blood-glucose tests 898
- BIO** Polarization analysis 897
- BIO** Honeybee navigation 898
- BIO** Wildlife tracking 901
- Colors of glowing objects 901
- BIO** Infrared sensors in snakes 902
- BIO** Seeing (infrared) 903
- Astronomical images 904
- Tethered satellite circuits 905
- BIO** Electromagnetic wave penetration 915
- Metal detectors 915

Chapter 26

- Transformers 919–921
- Charging electric toothbrushes 921
- Power transmission 922
- Household wiring 923–925
- BIO** Electrical safety 925–927
- The lightning crouch 927
- GFI circuits 927, 936
- Laptop trackpads 928
- Under-pavement car detectors 930
- Cleaning up computer power 931
- BIO** Nuclear magnetic resonance 934
- BIO** Cell membrane capacitance 943
- Halogen bulbs 943

Part VI Summary

- The greenhouse effect and global warming 945
- BIO** Taking x rays 946
- Electric cars 947
- Wireless power transmission 947

Chapter 27

- Global Positioning Systems 950, 960, 963, 976–977
- The Stanford Linear Accelerator 968
- Nuclear fission 976
- BIO** Pion therapy 985

Chapter 28

- BIO** Electron microscopy 986
- BIO** X-ray imaging 987
- BIO** X-ray diffraction of DNA 989
- BIO** Biological effects of UV 992
- BIO** Frequencies for photosynthesis 993
- BIO** Waves, photons, and vision 996
- BIO** Transmission electron microscopes 999–1000
- Scanning tunneling microscopy 1007
- BIO** Magnetic resonance imaging 1008–1009
- Electron diffraction 1017–1018
- Collisional excitation 1018

Chapter 29

- Spectroscopy 1020
- Colors of nebulae 1021
- Sodium filters for telescopes 1040
- BIO** Fluorescence 1041–1042
- BIO** LASIK surgery 1044
- Compact fluorescent lighting 1044–1045
- Light-emitting diodes 1053

Chapter 30

- Body scans 1054
- BIO** Deuterium and tracking migrating birds 1056
- Nuclear fusion in the sun 1059
- Nuclear power 1060
- Smoke detectors and sensing circuits 1063
- BIO** Beta decay in the human body 1065
- BIO** Food irradiation 1068
- BIO** Graves disease and radioactive iodine 1070
- Plutonium “batteries” 1071
- Radiocarbon dating 1072–1073
- BIO** Gamma-ray medical sterilization 1074
- BIO** Radiation dose from environmental sources 1074
- BIO** Nuclear medicine 1075–1076
- BIO** Nuclear imaging, PET scans 1076–1078
- Čerenkov radiation 1082
- BIO** Plutonium-powered exploration 1089
- Nuclear fission 1089

Part VII Summary

- Low-temperature physics 1091
- Splitting the atom 1092