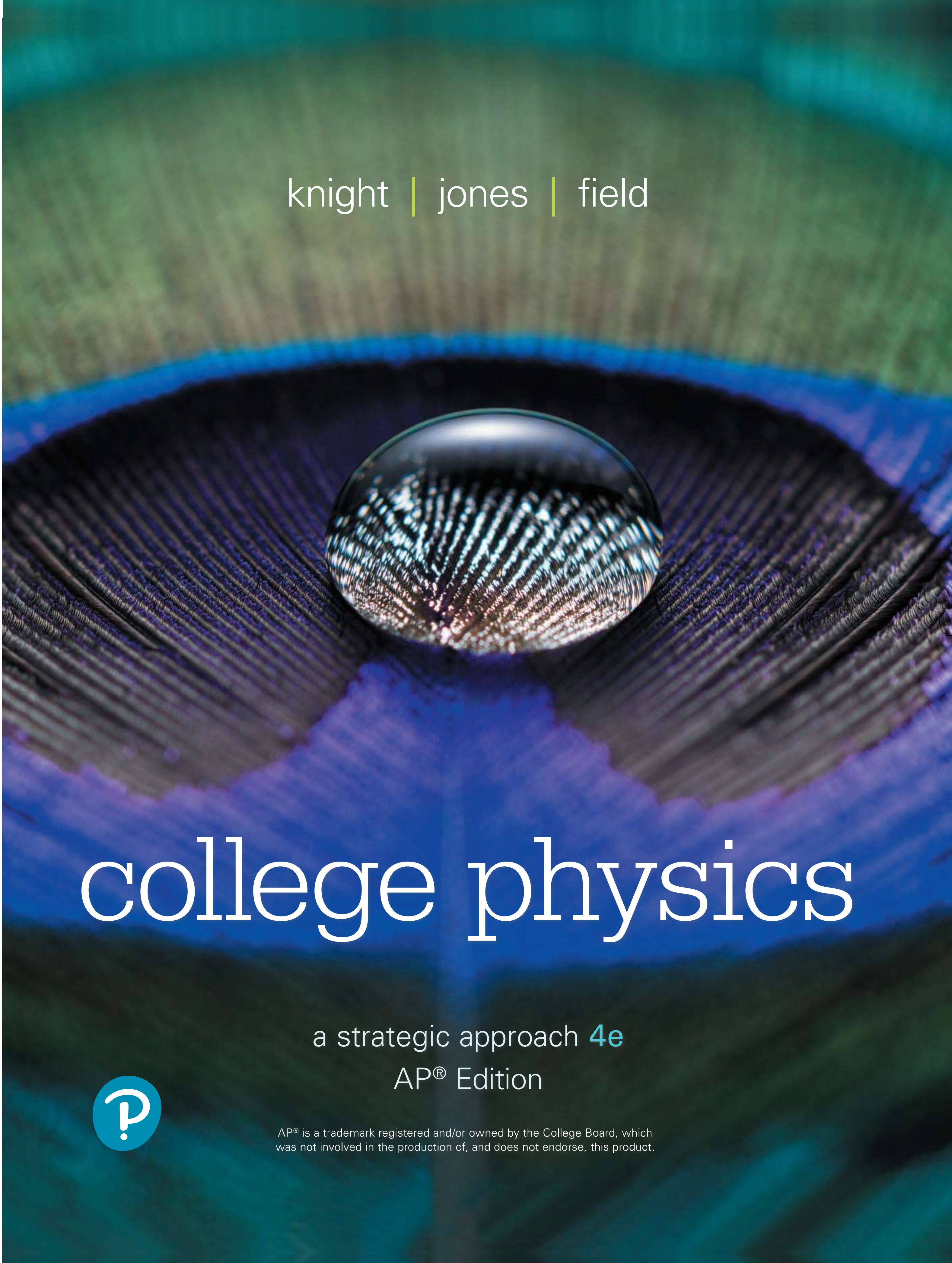


knight | jones | field

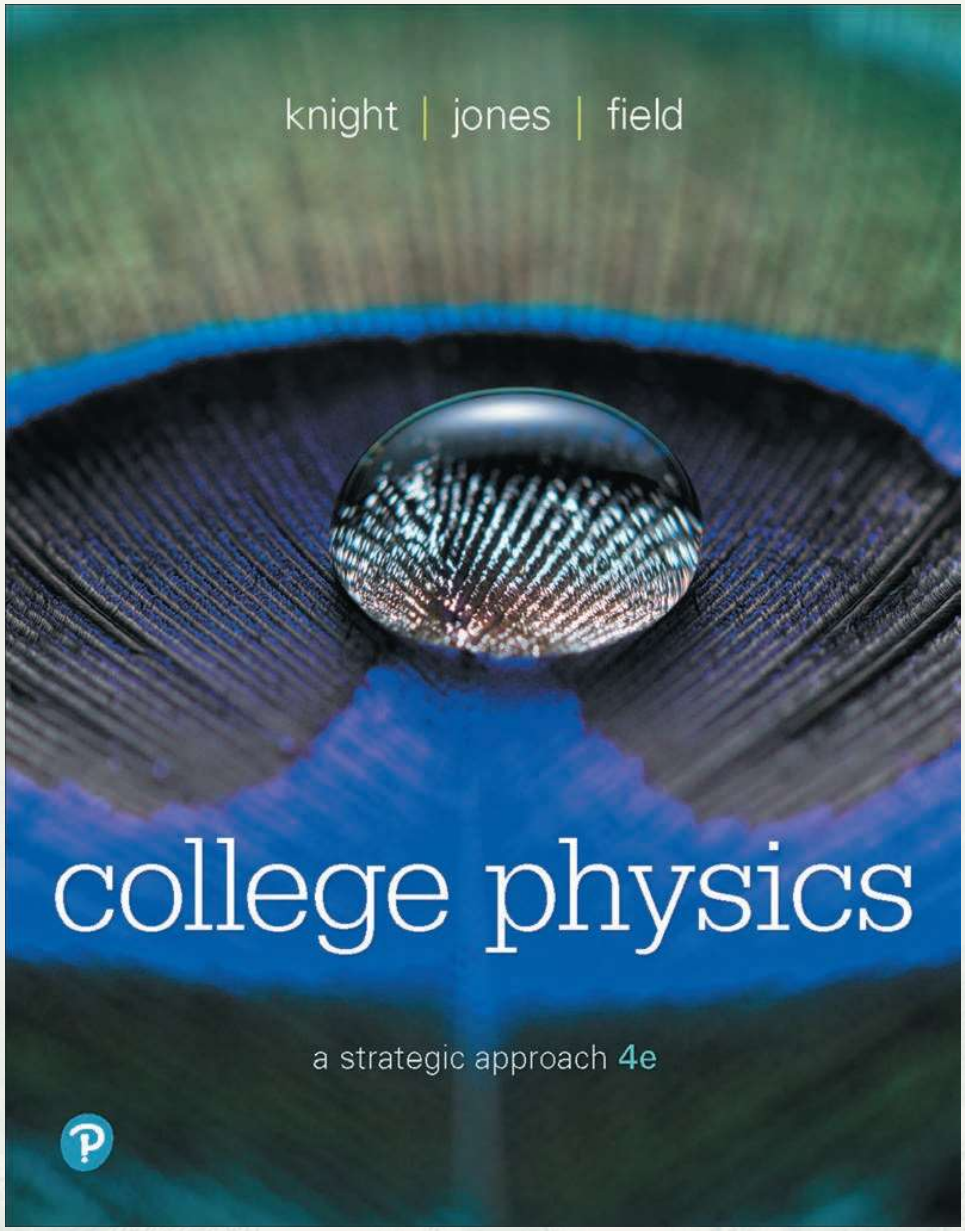
college physics

a strategic approach 4e

AP® Edition

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.



Pearson

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 BIO

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.

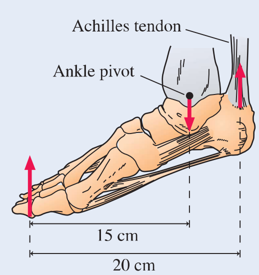
NEW! Topics of interest to life science students, such as the nature of the drag force at different scales and qualitative and quantitative descriptions of diffusion, provide current coverage of relevant topics based on the evolving consensus in the introductory physics for the life sciences community.

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 BIO

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** BIO

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 "pronk." A particular springbok goes into a crouch to perform a pronk. 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.

a. At what speed does the springbok leave the ground?
b. 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.

8. || BIO 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?

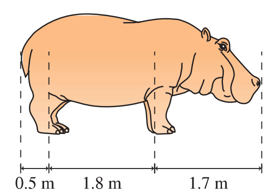


FIGURE P8.8

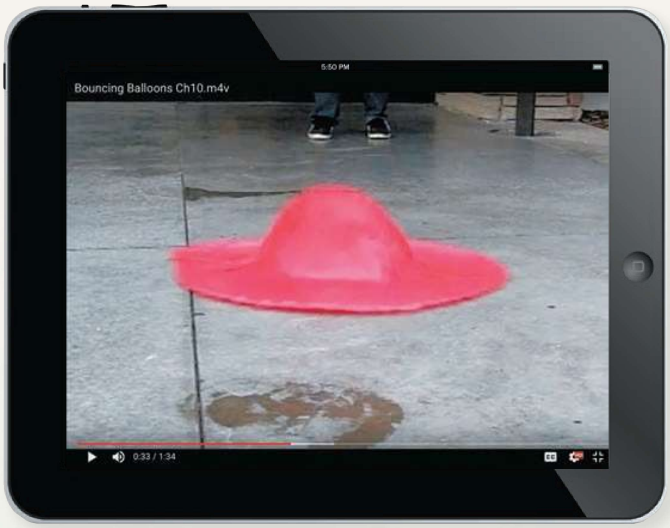
NEW! End-of-chapter problem sets now include real-life data and examples, helping students build transferable skills for their future courses and careers.

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:

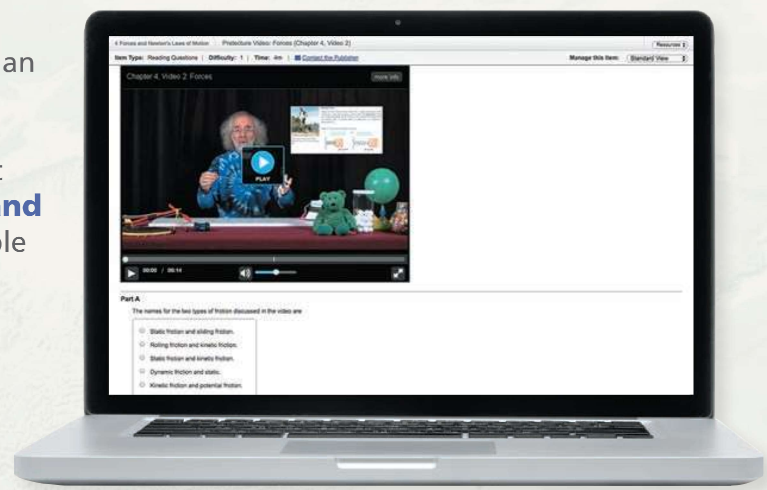
- Use motion diagrams to interpret motion. *Conceptual Question 2.3; Problems 2.1, 2.2, 2.59*
- Use and interpret motion graphs. *Conceptual Questions 2.5, 2.13; Problems 2.4, 2.18, 2.19, 2.22, 2.62*
- Calculate the velocity of an object. *Conceptual Question 2.9; Problems 2.8, 2.15, 2.57*
- Solve problems 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*

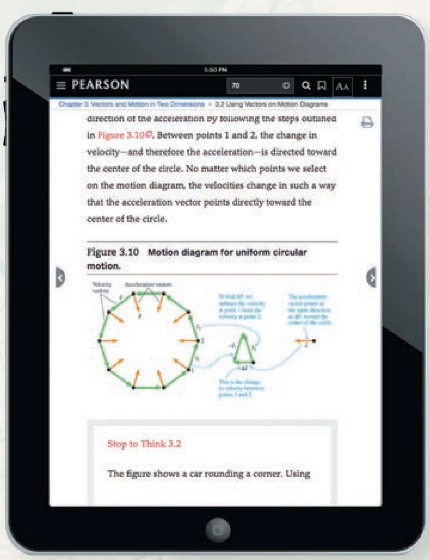
Prepare students for engagement



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.

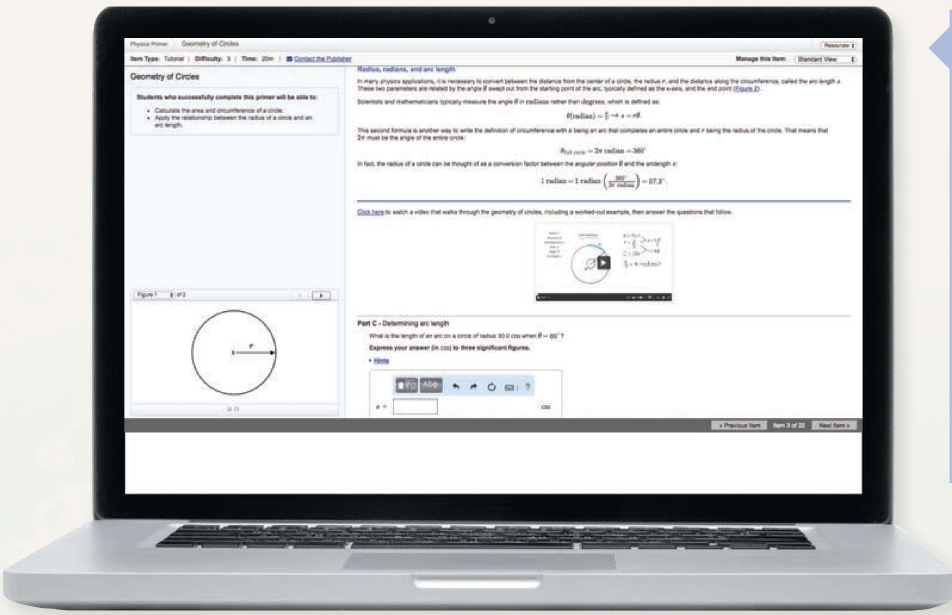
Prelecture Videos, presented by co-author Brian Jones, expand on the Chapter Previews, giving context, examples, and a chance for students to practice the concepts they are studying via short multiple-choice questions. **NEW! Qualitative and Quantitative prelecture videos** now available with assessment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



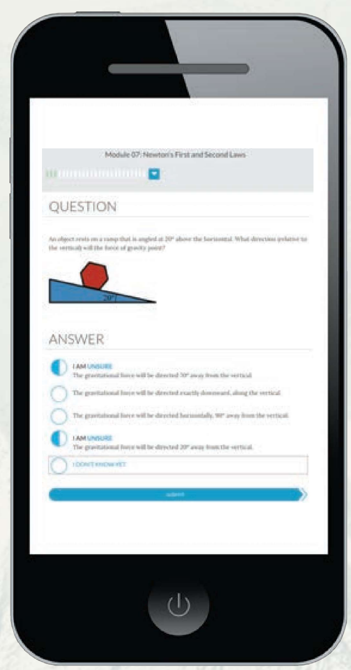


NEW! eText, optimized for mobile, seamlessly integrates videos and other rich media with the text and gives students access to their textbook anytime, anywhere. eText is available with Mastering Physics when packaged with new books, or as an upgrade students can purchase online.

in lecture with **interactive media**

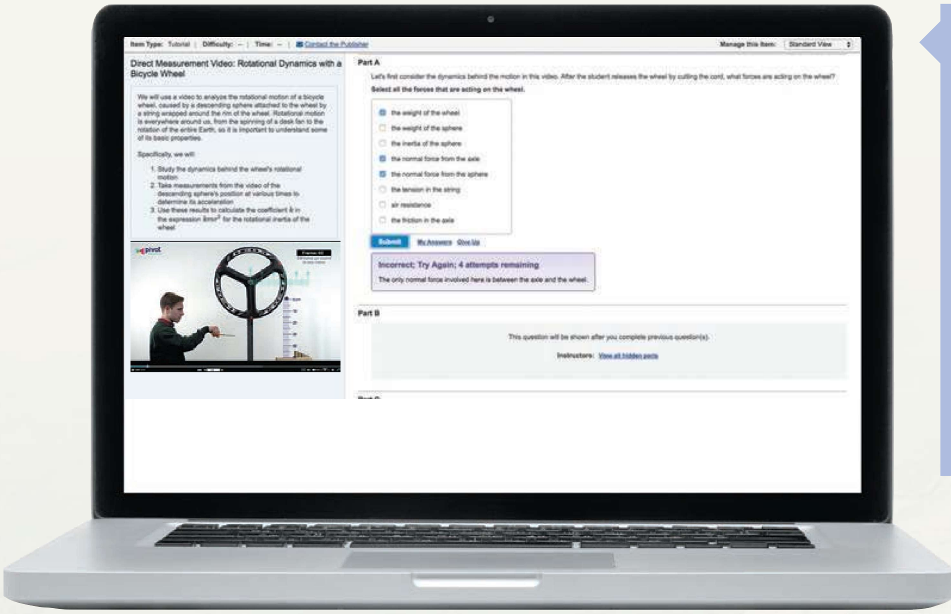


NEW! The Physics Primer relies on videos, hints, and feedback to refresh students' math skills in the context of physics and prepare them for success in the course. These tutorials can be assigned before the course begins as well as throughout the course. They ensure students practice and maintain their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

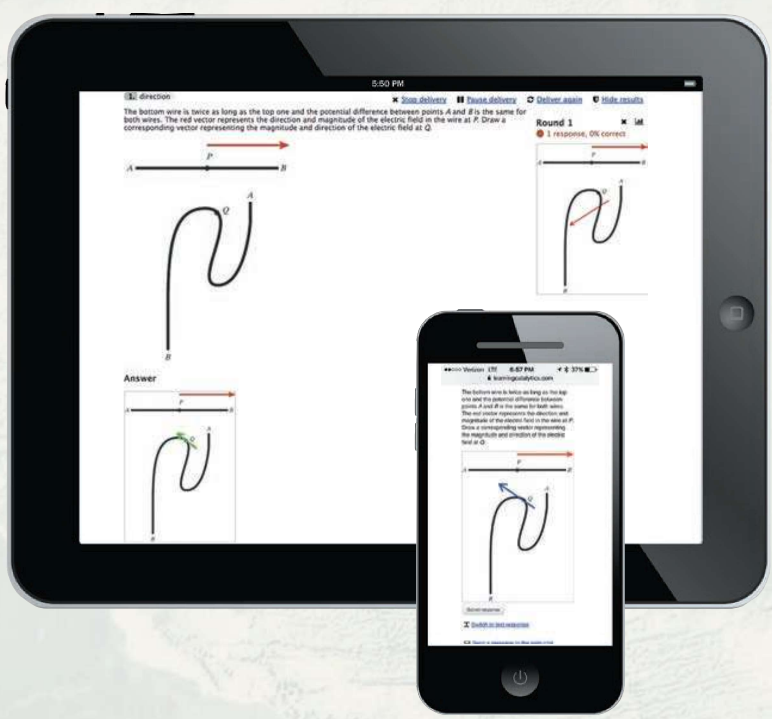
Enhance students' understanding



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.

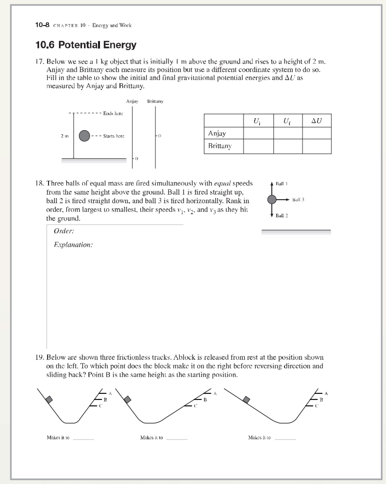


Supplements further enhance the learning experience

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.

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.

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)
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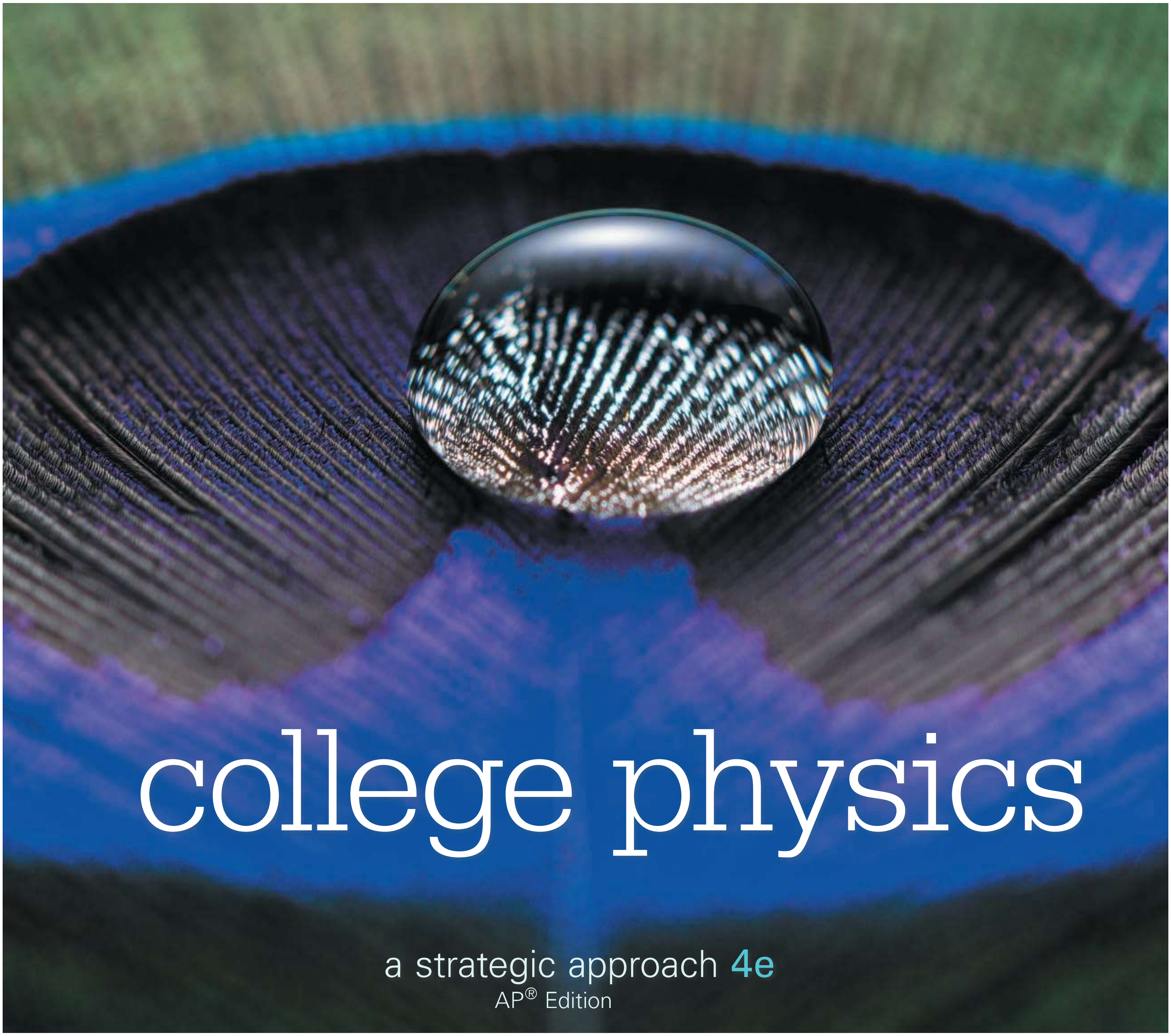
OR

- 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.



college physics

a strategic approach 4e

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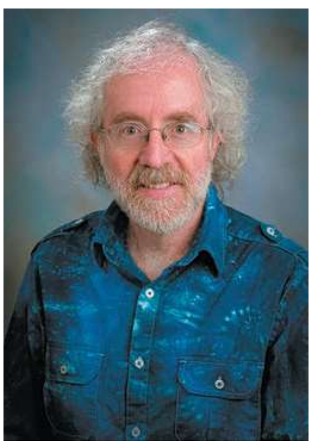
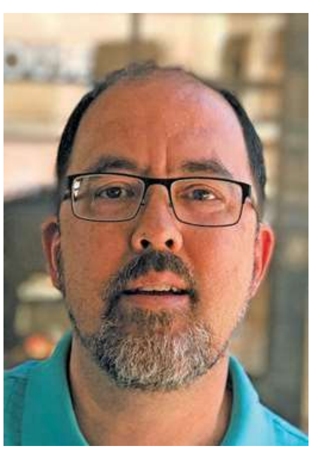
About the Authors

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.		Phys. 1	2.6, 7.2, 7.4, 9.4, 20.3, 30.7
1.A.2. Fundamental particles have no internal structure.	SP 1.1, 7.2	Phys. 2	28.3, 30.7
1.A.3. Nuclei have internal structures that determine their properties.		Phys. 2	29.2, 30.1, 30.2, 30.4, 30.5
1.A.4. Atoms have internal structures that determine their properties.	SP 1.1, 7.1	Phys. 2	29.2–29.7
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 *object*.	SP 1.1, 1.4, 7.1	Phys. 1, 2	11.3, 12.1, 12.2, 12.4, 12.5, 12.7, 12.8, 13.1

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.	SP 6.4, 7.2	Phys. 1, 2	20.1, 20.2, 22.1, 22.2
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.	SP 6.1, 6.2, 6.4, 7.2	Phys. 1, 2	20.1–20.3, 30.1, 30.7
1.B.3. The smallest observed unit of charge that can be isolated is the electron charge, also known as the elementary charge.	SP 1.5, 6.1, 7.2	Phys. 1, 2	20.1, 20.2, 29.2, 30.7

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.	SP 4.2	Phys. 1	4.5, 9.4–9.6
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.		Phys. 1	2.7, 6.5
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.	SP 4.2	Phys. 1	6.5
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.	SP 6.3	Phys. 2	27.10

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.	SP 6.3	Phys. 2	28.4

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 — Phys. 2	20.5

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 — Phys. 2	24.5
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 — Phys. 2	24.3, 24.4
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 — Phys. 2	24.7
2.D.4. Ferromagnetic materials contain magnetic domains that are themselves magnets. SP 1.4 — Phys. 2	24.8

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 — Phys. 2	21.4
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 — Phys. 2	21.4
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:

All forces share certain common characteristics when considered by observers in inertial reference frames.

	Chapter/Section
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 — Phys. 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
3.A.2. Forces are described by vectors. SP 1.1 — Phys. 1, 2	4.1, 4.4
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 — Phys. 1, 2	4.1, 4.2, 4.5, 5.1, 5.7, 6.2, 6.5, 9.2
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 — Phys. 1, 2	4.7, 5.7, 6.5, 9.4

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 — Phys. 1, 2	4.6, 5.1–5.3, 5.8, 5.9, 6.1, 20.3
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 — Phys. 1, 2	4.1–4.3, 4.6, 4.7, 5.1, 5.3, 5.8, 5.9, 6.1

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 $\vec{a} = \dfrac{\sum \vec{F}}{m}$.

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. — 9.4

SP 1.4, 2.2 — Phys. 1

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. — 9.2

SP 1.4, 2.2, 5.1 — Phys. 1

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. — 9.2–9.4

SP 2.2, 5.1 — Phys. 1

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. — 10.1–10.9, 21.1–21.4

SP 1.4, 2.1, 2.2, 6.4 — Phys. 1

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. — 10.1–10.3, 12.3

SP 1.4, 2.2, 6.4, 7.2 — Phys. 1

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. — 12.5, 12.6, 12.8

SP 6.4 — Phys. 2

4.C.4. Mass can be converted into energy and energy can be — 27.10, 30.2, 30.4

SP 2.2, 2.3, 7.2 — Phys. 2

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. — 7.2, 7.3, 8.1

SP 1.2, 1.4, 3.2, 4.1, 4.2, 5.1, 5.3 — Phys. 1

4.D.2. The angular momentum of a system may change due to interactions with other objects or systems. — 9.7

SP 1.2, 1.4, 4.2 — Phys. 1

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. — 9.7

SP 2.2, 4.1, 4.2 — Phys. 1

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. — 24.8

SP 1.1, 1.4, 2.2 — Phys. 2

4.E.2. Changing magnetic flux induces an electric field that can establish an induced emf in a system. — 25.1–25.4

SP 6.4 — Phys. 2

4.E.3. The charge distribution in a system can be altered by the effects of electric forces produced by a charged object. — 20.1, 20.2, 22.1, 22.2

SP 1.1, 1.4, 3.2, 4.1, 4.2, 5.1, 5.3, 6.4, 7.2 — Phys. 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. — 20.5, 21.7, 22.4, 22.5, 22.6

SP 2.2, 4.1, 4.2, 5.1, 6.4 — Phys. 2

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. — 23.1–23.7

SP 2.2, 4.2, 5.1, 6.1, 6.4 — Phys. 2

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. — 9.4

Phys. 1

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	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	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—isovolumetric 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.] SP 1.4, 2.2, 4.1, 4.2, 5.1, 6.4, 7.2 — Phys. 1, 2	22.1, 22.2, 23.2, 23.6–23.8

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. SP 2.1, 2.2, 3.2, 4.2, 5.1, 5.3, 6.4, 7.2 — Phys. 1, 2	9.4, 10.9
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. SP 2.1, 2.2, 4.1, 4.2, 4.4, 5.1, 5.3, 6.4, 7.2 — Phys. 1, 2	9.4–9.6, 10.9
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.] SP 6.4 — Phys. 1, 2	7.3

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. SP 2.1, 2.2, 6.4, 7.2 — Phys. 1	9.7
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. SP 2.2 — Phys. 1	9.7

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. SP 2.1, 2.2, 7.2 — Phys. 2	13.4

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. SP 6.4 — Phys. 2	30.2, 30.4

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. SP 1.2, 5.1, 6.2 — Phys. 1, 2	15.1, 25.5
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. SP 6.4, 7.2 — Phys. 1, 2	15.1, 15.2, 15.4, 25.5
6.A.3. The amplitude is the maximum displacement of a wave from its equilibrium value. SP 1.4 — Phys. 1	15.3
6.A.4. Classically, the energy carried by a wave depends upon and increases with amplitude. Examples should include sound waves. SP 6.4 — Phys. 1	15.5, 15.6, 25.5

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.			15.3, 25.5
	SP 1.4, 2.2	Phys. 1	
6.B.2. For a periodic wave, the wavelength is the repeat distance of the wave.			15.3, 25.5
	SP 1.4	Phys. 1	

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.			15.3, 25.5
	SP 1.5	Phys. 2	
6.B.4. For a periodic wave, wavelength is the ratio of speed over frequency.			15.3, 25.5
	SP 4.2, 5.1, 7.2	Phys. 1	
6.B.5. The observed frequency of a wave depends on the relative motion of source and observer. This is a qualitative treatment only.			15.7
	SP 1.4	Phys. 1	

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.			16.1
	SP 1.4, 6.4, 7.2	Phys. 2	
6.C.2. When waves pass through an opening whose dimensions are comparable to the wavelength, a diffraction pattern can be observed.			17.1, 17.5, 17.6, 28.1, 28.4
	SP 1.4, 6.4, 7.2	Phys. 2	
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.			17.2–17.4
	SP 1.4, 6.4	Phys. 2	
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.			17.1
	SP 6.4, 7.2	Phys. 2	

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.			16.1
	SP 1.1, 1.4, 4.2, 5.1	Phys. 1	
6.D.2. Two or more traveling waves can interact in such a way as to produce amplitude variations in the resultant wave.			16.7
	SP 5.1	Phys. 1	
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.			16.2–16.4
	SP 1.2, 2.1, 3.2, 4.1, 4.2, 5.1, 5.2, 5.3, 6.4	Phys. 1	
6.D.4. The possible wavelengths of a standing wave are determined by the size of the region to which it is confined.			16.2–16.4
	SP 1.5, 2.2, 6.1	Phys. 1	
6.D.5. Beats arise from the addition of waves of slightly different frequency.			16.7
	SP 1.2	Phys. 1	

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.)			18.1
	SP 6.4, 7.2	Phys. 2	
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.			18.2
	SP 6.4, 7.2	Phys. 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.			18.3
	SP 1.1, 1.4, 4.1, 5.1, 5.2, 5.3, 6.4, 7.2	Phys. 2	

6.E.4. The reflection of light from surfaces can be used to form images. — 18.2
SP 1.4, 2.2, 3.2, 4.1, 5.1, 5.2, 5.3 — Phys. 2

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

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. — 15.1, 15.4, 25.5
SP 6.4, 7.2 — Phys. 2

6.F.2. Electromagnetic waves can transmit energy through a medium and through a vacuum. — 15.1, 15.4, 25.5
SP 1.1 — Phys. 2

6.F.3. Photons are individual energy packets of electromagnetic waves, with $E_{photon} = hf$, where h is Planck's constant and f is the frequency of the associated light wave. — 28.2, 28.3, 28.6
SP 6.4 — Phys. 2

6.F.4. The nature of light requires that different models of light are most appropriate at different scales. — 28.3
SP 6.4, 7.1 — Phys. 2

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. — 28.4
SP 6.4, 7.1 — Phys. 2

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. — 28.4
SP 6.1, 6.4 — Phys. 2

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. — 12.2
SP 1.4, 2.2, 6.4, 7.2 — Phys. 2

7.A.2. The temperature of a system characterizes the average kinetic energy of its molecules. — 11.3, 12.2
SP 7.1 — Phys. 2

7.A.3. In an ideal gas, the macroscopic (average) pressure (P), temperature (T), and volume (V), are related by the equation $PV = nkT$. — 12.2, 12.3
SP 3.2, 4.2, 5.1, 6.4, 7.2 — Phys. 2

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. — 11.3, 11.4, 12.5, 12.8
SP 6.2 — Phys. 2

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. — 11.7
SP 7.1 — Phys. 2

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.) — 28.4
SP 1.4 — Phys. 2

7.C.2. The allowed states for an electron in an atom can be calculated from the wave model of an electron. — 28.4–28.6
SP 1.4 — Phys. 2

7.C.3. The spontaneous radioactive decay of an individual nucleus is described by probability. — 30.1, 30.4, 30.5
SP 6.4 — Phys. 2

7.C.4. Photon emission and absorption processes are described by probability. — 28.6, 29.3, 29.4, 29.7, 29.9
SP 1.1, 1.2 — Phys. 2

Detailed Contents

PART VI Electricity and Magnetism

PART VII Modern Physics

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.