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.

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?
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 \( 35 \, \text{m/s}^2 \) 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!** 

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

---

NEW! 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

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! 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.

**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.
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.

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.
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.

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.
they apply what they’ve learned

10-8  Chapter 10 · Energy and Work

10.6 Potential Energy

17. Below we see a 1 kg object that is initially 1 m above the ground and rises to a height of 2 m. Anjay and Brittany 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 Anjay and Brittany.

<table>
<thead>
<tr>
<th></th>
<th>Initial Energy</th>
<th>Final Energy</th>
<th>ΔU</th>
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<td></td>
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<tr>
<td>Brittany</td>
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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 B is the same height as the starting position.

Makes it to ____________

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.
Instructor tools help shape your course more efficiently

NEW! 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.
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 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.

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. Please request a copy from your local Pearson sales representative if it is of interest to you (ISBN 978-0-80538702-5).

What’s New to This Edition

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 to present concepts and problem-solving strategies in an engaging and effective manner. In this 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.

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.
Preface to the Instructor

- 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.
Preface to the Instructor

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


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.
## Instructional Package

*College Physics: A Strategic Approach*, fourth edition, provides an integrated teaching and learning package of support material for students and instructors.

**NOTE** For convenience, most instructor supplements can be downloaded from the “Instructor Resources” area of Mastering Physics and the Instructor Resource Center (www.pearson.com/us/higher-education/customers/educators.html).

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<th>Print</th>
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<td>Mastering Physics with Pearson eText</td>
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<td>Instructor and Student Supplement</td>
<td>This product features all the resources of Mastering Physics in addition to the new Pearson eText 2.0. Now available on smartphones and tablets, Pearson eText 2.0 comprises the full text, including videos and other rich media.</td>
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<td>This comprehensive solutions manual contains complete solutions to all end-of-chapter questions and problems.</td>
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<td>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 format.</td>
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<td>Instructor Supplement</td>
<td>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.</td>
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<tr>
<td>Volume 1 (CH1–16) (ISBN 0134609891X)</td>
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<td>Student’s Solutions Manual</td>
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<td>These solutions manuals contain detailed solutions to all of the odd-numbered end-of-chapter problems from the textbook.</td>
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The Student Workbook

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.

The workbook exercises, which are generally qualitative and/or graphical, draw heavily upon the physics education research literature. The exercises deal with issues known to cause student difficulties and employ techniques that have proven to be effective at overcoming those difficulties. Also included are jeopardy problems that ask students to work backward from equations to physical situations, enhancing their understanding and critical thinking skills. The workbook exercises can be used in-class as part of an active-learning teaching strategy, in recitation sections, or as homework. More information about effective use of the Student Workbook can be found in the Instructor’s Guide in the Ready-to-Go modules.


Acknowledgments

We have relied upon conversations with and, especially, the written publications of many members of the physics education community. Those who may recognize their influence include the late Arnold Arons, Uri Ganiel, Fred Goldberg, Ibrahim Halloun, Paula Heron, David Hestenes, the late Leonard Jossem, Jill Larkin, Priscilla Laws, John Mallinckrodt, Richard Mayer, Lillian McDermott and members of the Physics Education Research Group at the University of Washington, Edward “Joe” Redish, Fred Reif, Rachel Scherr, Bruce Sherwood, David Sokoloff, Ronald Thornton, Sheila Tobias, Alan Van Heuvelen, Carl Wieman, and Michael Wittman.

We are very grateful to Larry Smith for the difficult task of writing the Instructor Solutions Manual; to Scott Nutter for writing out the Student Workbook answers; to Wayne Anderson, Jim Andrews, Nancy Beverly, David Cole, Karim Diff, Jim Dove, Marty Gelfand, Kathy Harper, Charlie Hibbard, Robert Lutz, Matt Moelter, Kandiah Manivannan, Ken Robinson, Cindy Schwarz-Rachmilotwitz, and Rachel Jones for their contributions to the end-of-chapter questions and problems; to Wayne again for helping with the Test Bank questions; and to Steven Vogel for his careful review of the biological content of many chapters and for helpful suggestions.

We especially want to thank Editor-in-Chief, Director Physical Science Courseware Portfolio, Jeanne Zalesky; Editor, Physics Courseware Portfolio Analyst, Darien Estes; Courseware Director, Content Development, Jennifer Hart; Senior Analyst, Courseware Development, Suzanne Olivier; Senior Content Producer, Martha Steele; and all the other staff at Pearson for their enthusiasm and hard work on this project. Having a diverse author team is one of the strengths of this book, but it has meant that we rely a great deal on Darien to help us keep to a single focus. Special thanks is due Martha for her keen attention to all details, careful scheduling and shepherding of all the elements of this complex project, and gentle prodding to keep everything moving forward.

Rose Kernan and the team at Nesbitt Graphics/Cenvo, copy editor Carol Reitz, and photo researcher Dena Digilio get much credit for making this complex project all come together. In addition to the reviewers and classroom testers listed below, who gave invaluable feedback, we are particularly grateful to Ansel Foxley for his close scrutiny of every word, symbol, number, and figure.

Randy Knight: I would like to thank my Cal Poly colleagues for many valuable conversations and suggestions. I am endlessly grateful to my wife Sally for her love, encouragement, and patience, and to our many cats for nothing in particular other than being cats.

Brian Jones: I would like to thank my fellow AAPT and PIRA members for their insight and ideas, the students and colleagues who are my partners in the Little Shop of Physics, the students in my College Physics classes who teach me so much about the world, and the team at Pearson who help me develop as an educator and writer. Most of all, I thank my wife Carol, my best friend and gentlest editor, whose love makes the journey worthwhile.

Stuart Field: I would like to thank my wife Julie and my children, Sam and Ellen, for their love, support, and encouragement.
Preface to the Instructor

Reviewers and Classroom Testers

Reviewers for the Fourth Edition
Eduardo Araujo, Miami Dade College
Landon Bellavia, The University of Findlay
John Calarco, University of New Hampshire
Josh Colwell, University of Central Florida
Daniel Constantino, Pennsylvania State University
Chad Davies, Gordon College
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About the Cover

The cover image isn’t just a pretty picture. All of the elements—the lensing by the water droplet, the structure of the feather, the mechanism for the feather colors—make an appearance as applications of the physics concepts that students are learning.
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.
If you are taking the College Physics course, there’s a good chance that you are majoring in the biological sciences. There’s also a good chance that you are preparing for a career in the health professions, and so might well be required to take the Medical College Admission Test, the MCAT exam.

The *Chemical and Physical Foundations of Biological Systems* section of the MCAT assesses your understanding of the concepts of this course by testing your ability to apply these concepts to living systems. You will be expected to use what you’ve learned to analyze situations you’ve never seen before, making simplified but realistic models of the world. Your reasoning skills will be just as important as your understanding of the universal laws of physics.

**Structure of the MCAT Exam**

Most of the test consists of a series of passages of technical information followed by a series of questions based on each passage, much like the passage problems at the end of each chapter in this book. Some details:

- The passages and the questions are always integrated. Understanding the passage and answering the questions will require you to use knowledge from several different areas of physics.
- Passages will generally be about topics for which you do not have detailed knowledge. But, if you read carefully, you’ll see that the treatment of the passage is based on information you should know well.
- The test assumes a basic level of background knowledge. You’ll need to have facility with central themes and major concepts, but you won’t need detailed knowledge of any particular topic. Such detailed information, if needed, will be provided in the passage.
- You can’t use calculators on the test, so any math that you do will be reasonably simple. Quickly estimating an answer with ratio reasoning or a knowledge of the scale of physical quantities will be a useful skill.
- The answers to the questions are all designed to be plausible. You can’t generally weed out the “bad” answers with a quick inspection.
- The test is given online. Practicing with Mastering Physics will help you get used to this format.

**Preparing for the Test**

Because you have used this book as a tool for learning physics, you should use it as a tool for reviewing for the MCAT exam. Several of the key features of the book will be useful for this, including some that were explicitly designed with the MCAT exam in mind.

As you review the chapters:

- Start with the Chapter Previews, which provide a “big picture” overview of the content. What are the major themes of each chapter?
- Look for the Synthesis boxes that bring together key concepts and equations. These show connections and highlight differences that you should understand and be ready to apply.
- Go through each chapter and review the Stop to Think exercises. These are a good way to test your understanding of the key concepts and techniques.
- Each chapter closes with a passage problem that is designed to be “MCAT-exam-like.” They’ll give you good practice with the “read a passage, answer questions” structure of the MCAT exam.

The passage problems are a good tool, but the passages usually don’t integrate topics that span several chapters—a key feature of the MCAT exam. For integrated passages and problems, turn to the Part Summaries:

- For each Part Summary, read the One Step Beyond passage and answer the associated questions.
- After this, read the passages and answer the questions that end each Part Summary section. These passages and associated problems are—by design—very similar to the passages and questions you’ll see on the actual MCAT exam.

**Taking the Test: Reading the Passage**

As you read each passage, you’ll need to interpret the information presented and connect it with concepts you are familiar with, translating it into a form that makes sense based on your background.

The next page shows a passage that was written to very closely match the style and substance of an actual MCAT passage. Blue annotations highlight connections you should make as you read. The passage describes a situation (the mechanics and energetics of sled dogs) that you probably haven’t seen before. But the basic physics (friction, energy conversion) are principles that you are familiar with, principles that you have seen applied to related situations. When you read the passage, think about the underlying physics concepts and how they apply to this case.
Translating the Passage
As you read the passage, do some translation. Connect the scenario to examples you’ve seen before, translate given information into forms you are familiar with, think about the basic physical principles that apply.

Passage X
For travel over snow, a sled with runners that slide on snow is the best way to get around. Snow is slippery, but there is still friction between runners and the ground; the forward force required to pull a sled at a constant speed might be 1/6 of the sled’s weight.

The pulling force might well come from a dog. In a typical sled, the rope that the dog uses to pull attaches at a slight angle, as in Figure 1. The pulling force is the horizontal component of the tension in the rope.

figure 1
Sled dogs have great aerobic capacity; a 40 kg dog can provide output power to pull with a 60 N force at 2.2 m/s for hours. The output power is related to force and velocity by $P = F \cdot v$, so they can pull lighter loads at higher speeds.

Doing 100 J of work means that a dog must expend 400 J of metabolic energy. The difference must be exhausted as heat; given the excellent insulation provided by a dog’s fur, this is mostly via evaporation as it pants. At a typical body temperature, the evaporation of 1.0 l of water carries away 240,000 J, so this is an effective means of cooling.

As you read this part of the passage, think about the forces involved: For a sled moving at a constant speed, there is no net force. The downward weight force is equal to the upward normal force; the forward pulling force must be equal to the friction force, which is acting opposite the sled’s motion. There are many problems like this in Chapter 5.

Part of translating is converting given information into a more usual or more useful form. This is really a statement about the coefficient of kinetic friction.

The force applied to the sled is the tension force in the rope, which is shown at an angle. The horizontal component is the pulling force; you’re told this. There is a vertical component of the force as well.

In the data given here, and the description given above, the sled moves at a constant speed—there is no mention of acceleration anywhere in this passage. In such cases, the net force is zero and the kinetic energy of the sled isn’t changing.

Notice that the key equation relating power, force, and velocity is given to you. That’s to be expected. Any specific information, including equations, constants, and other such details, will generally be given in the passage. The MCAT is a test of reasoning, not recall.

The concepts of metabolic energy and energy output are treated in Chapter 11. The details here match those in the chapter (as they should!); this corresponds to an efficiency of 25%. 400 J of energy is used by the body; 25% of this, 100 J, is the energy output. This means that 300 J is exhausted as heat.

Chapter 12 discusses means of heat transfer: conduction, convection, radiation, evaporation. This paragraph gives biological details about dogs that you can interpret as follows: A dog’s fur limits transfer by conduction, convection, and radiation; evaporation of water by a panting dog must take up the slack.

The specific data for energy required to evaporate water are given. If you need such information to answer questions, it will almost certainly be provided. As we noted above, this is a test of reasoning, not recall.
Taking the Test: Answering the Questions
The passages on the MCAT exam seem complicated at first, but, as we’ve seen, they are about basic concepts and central themes that you know well. The same is true of the questions; they aren’t as difficult as they may seem at first. As with the passage, you should start by translating the questions, identifying the physical concepts that apply in each case. You then proceed by reasoning, determining the solution to the question, using your understanding of these basic concepts. The practical suggestions below are followed by a detailed overview of the solutions to the questions based on the passage on the previous page.

You Can Answer the Questions in Any Order
The questions test a range of skills and have a range of difficulties. Many questions will involve simple reading comprehension; these are usually quite straightforward. Some require sophisticated reasoning and (slightly) complex mathematical manipulations. Start with the easy ones, ones that you can quickly solve. Save the more complex ones for later, and skip them if time is short.

Take Steps to Simplify or Eliminate Calculations
You won’t be allowed to use a calculator on the exam, so any math that you do will be reasonably straightforward. To rapidly converge on a correct answer choice, there are some important “shortcuts” that you can take.

- Use ratio reasoning. What’s the relationship between the variables involved in a question? You can use this to deduce the answer with only a very simple calculation, as we’ve seen many times in the book. For instance, suppose you are asked the following question:

  A model rocket is powered by chemical fuel. A student launches a rocket with a small engine containing 1.0 g of combustible fuel. The rocket reaches a speed of 10 m/s. The student then launches the rocket again, using an engine with 4.0 g of fuel. If all other parameters of the launch are kept the same, what final speed would you expect for this second trial?

This is an energy conversion problem: Chemical energy of the fuel is converted to kinetic energy of the rocket. Kinetic energy is related to the speed by \( K = \frac{1}{2}m v^2 \). The chemical energy—and thus the kinetic energy—in the second trial is increased by a factor of 4. Since \( K \sim v^2 \), the speed must increase by a factor of 2, to 20 m/s.

- Simplify calculations by liberally rounding numbers. You can round off numbers to make calculations more straightforward. Your final result will probably be close enough to choose the correct answer from the list given. For instance, suppose you are asked the following question:

  A ball moving at 2.0 m/s rolls off the edge of a table that’s 1.2 m high. How far from the edge of the table does the ball land?

  A. 2 m  B. 1.5 m  C. 1 m  D. 0.5 m

We know that the vertical motion of the ball is free fall; so the vertical distance fallen by the ball in a time \( \Delta t \) is \( \Delta y = -\frac{1}{2}gt^2 \). The time to fall 1.2 m is \( \Delta t = \sqrt{\frac{2 \cdot 1.2 \text{ m}}{g}} \). Rather than complete this calculation, we estimate the result as follows: \( \Delta t = \sqrt{\frac{2 \cdot 4.9 \text{ m/s}^2}{8}} = \sqrt{\frac{1}{4}} = 1/2 = 0.5 \text{s} \).

During this free-fall time, the horizontal motion is constant at 2.0 m/s, so we expect the ball to land about 1 m away. Our quick calculation shows us that the correct answer is choice C—no other answer is close.

- For calculations using values in scientific notation, compute either the first digits or the exponents, not both. In some cases, a quick calculation can tell you the correct leading digit, and that’s all you need to figure out the correct answer. In other cases, you’ll find possible answers with the same leading digit but very different exponents or decimal places. In this case, all you need is a simple order-of-magnitude estimate to decide on the right result.

- Where possible, use your knowledge of the expected scale of physical quantities to quickly determine the correct answer. For instance, suppose a question asks you to find the photon energy for green light of wavelength 550 nm. Visible light has photon energies of about 2 eV, or about \( 3 \times 10^{-19} \text{ J} \), and that might be enough information to allow you to pick out the correct answer with no calculation.

- Beware of “distractors,” answers that you’ll get if you make common mistakes. For example, Question 4 on the next page is about energy conversion. The dog is keeping the sled in motion, so it’s common for students to say that the dog is converting chemical energy in its body into kinetic energy. However, the kinetic energy isn’t changing. The two answer choices that involve kinetic energy are common, but incorrect, choices. Be aware that the questions are constructed to bring out such misconceptions and that these tempting, but wrong, answer choices will be provided.

One Final Tip: Look at the Big Picture
The MCAT exam tests your ability to look at a technical passage about which you have some background knowledge and quickly get a sense of what it is saying, enough to answer questions about it. Keep this big picture in mind:

- Don’t get bogged down in technical details of the particular situation. Focus on the basic physics.
- Don’t spend too much time on any one question. If one question is taking too much time, make an educated guess and move on.
- Don’t get confused by details of notation or terminology. For instance, different people use different symbols for physical variables. In this text, we use the symbol \( K \) for kinetic energy; others use \( E_k \).

Finally, don’t forget the most important aspect of success on the MCAT exam: The best way to prepare for this or any test is simply to understand the subject. As you prepare for the test, focus your energy on reviewing and refining your knowledge of central topics and techniques, and practice applying your knowledge by solving problems like you’ll see on the actual MCAT.
Increasing speed increases power, as the passage told us. But the energy to pull the sled is not the power, it's the work, and we know that the work is $W = F \Delta x$.

This is a question about work and energy, not about power.

1. What is the approximate coefficient of kinetic friction for a sled on snow?
   - A. 0.35
   - B. 0.25
   - C. 0.15
   - D. 0.05

2. If a rope pulls at an angle, as in Figure 1, how will this affect the pulling force necessary to keep the sled moving at a constant speed?
   - A. This will reduce the pulling force.
   - B. This will not change the pulling force.
   - C. This will increase the pulling force.
   - D. It will increase or decrease the pulling force, depending on angle.

3. A dog pulls a 40 kg sled at a maximum speed of 2 m/s. What is the maximum speed for an 80 kg sled?
   - A. 2 m/s
   - B. 1.5 m/s
   - C. 1.0 m/s
   - D. 0.5 m/s

4. As a dog pulls a sled at constant speed, chemical energy in the dog's body is converted to
   - A. kinetic energy
   - B. thermal energy
   - C. kinetic energy and thermal energy
   - D. kinetic energy and potential energy

5. A dog pulls a sled for a distance of 1.0 km at a speed of 1 m/s, requiring an energy output of 60,000 J. If the dog pulls the sled at 2 m/s, the necessary energy is
   - A. 240,000 J
   - B. 120,000 J
   - C. 60,000 J
   - D. 30,000 J

6. A dog uses 100,000 J of metabolic energy pulling a sled. How much energy must the dog exhaust by panting?
   - A. 100,000 J
   - B. 75,000 J
   - C. 50,000 J
   - D. 25,000 J

Choice B is correct, but A and C are clever distractors. It's tempting to choose an answer that includes kinetic energy. The sled is in motion, after all! But don't be swayed. The kinetic energy isn't changing, and friction to the sled converts any energy the dog supplies into thermal energy.

Doubling the speed doubles the power, but it doesn't change the force; that's fixed by friction. The distance is the same as well, and so is the work done, the energy required. Since the speed doubles, it's tempting to think the energy doubles, though. This "obvious" but incorrect solution is one of the choices—expect such situations on the actual MCAT.

If 75% of the energy must be exhausted to the environment, that's 75,000 J.
Real-World Applications

Applications of biological or medical interest are marked with 80 in the list below, including MCAT-style Passage Problems. Other end-of-chapter problems of biological or medical interest are marked 80 in the chapter.

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- One Step Beyond
  - The Greenhouse Effect and Global Warming

### Part VI Problems

- Electricity and Magnetism
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