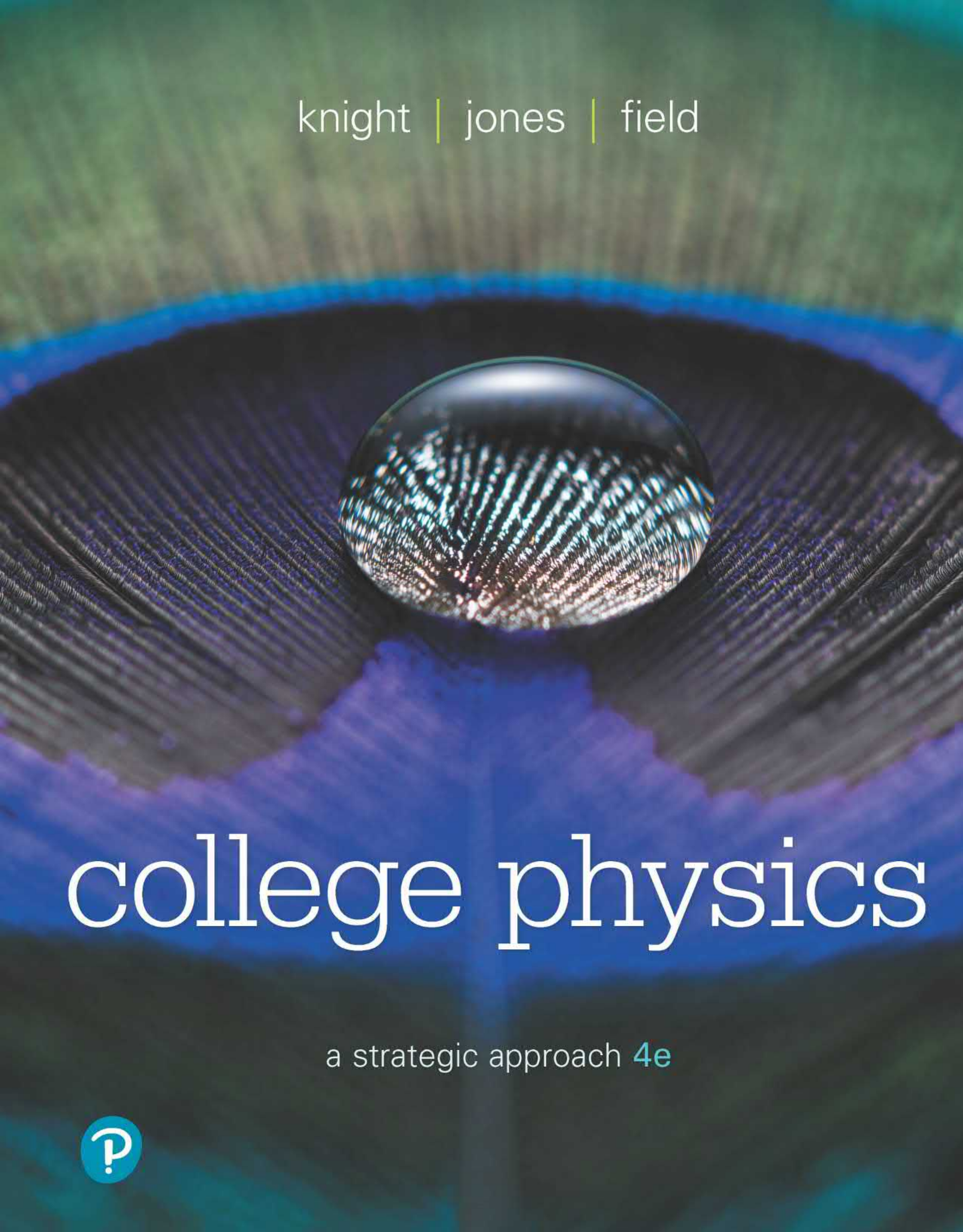

knight | jones | field

college physics

a strategic approach 4e

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Useful Data

Planetary data and gravity

M_e	Mass of the earth	5.98×10^{24} kg
R_e	Radius of the earth	6.37×10^{6} m
g	Free-fall acceleration	$9.80\ \mathrm{m/s^2}$
G	Gravitational constant	$6.67 \times 10^{-11}\ \mathrm{N \cdot m^2/kg^2}$

Thermodynamics

k_B	Boltzmann's constant	1.38×10^{-23} J/K
R	Gas constant	8.31 J/mol · K
N_A	Avogadro's number	6.02×10^{23} particles/mol
T_0	Absolute zero	−273°C
p_{atm}	Standard atmosphere	101,300 Pa

Speeds of sound and light

v_{sound}	Speed of sound in air at 20°C	343 m/s
c	Speed of light in vacuum	3.00×10^{8} m/s

Particle masses

m_p	Mass of the proton (and the neutron)	1.67×10^{-27} kg
m_n	Mass of the neutron	1.67×10^{-27} kg
m_e	Mass of the electron	9.11×10^{-31} kg

Electricity and magnetism

K	Coulomb's law constant $(1/4\pi\epsilon_0)$	$8.99 \times 10^{9}\ \mathrm{N \cdot m^2/C^2}$
ϵ_0	Permittivity constant	$8.85 \times 10^{-12}\ \mathrm{C^2/N \cdot m^2}$
μ_0	Permeability constant	1.26×10^{-6} T · m/A
e	Fundamental unit of charge	1.60×10^{-19} C

Quantum and atomic physics

h	Planck's constant	6.63×10^{-34} J · s	4.14×10^{-15} eV · s
$\hbar$	Planck's constant	1.05×10^{-34} J · s	6.58×10^{-16} eV · s
a_B	Bohr radius	5.29×10^{-11} m	

Common Prefixes

Prefix	Meaning
femto-	10^{-15}
pico-	10^{-12}
nano-	10^{-9}
micro-	10^{-6}
milli-	10^{-3}
centi-	10^{-2}
kilo-	10^{3}
mega-	10^{6}
giga-	10^{9}
terra-	10^{12}

Conversion Factors

Length
1 in = 2.54 cm
1 mi = 1.609 km
1 m = 39.37 in
1 km = 0.621 mi

Velocity
1 mph = 0.447 m/s
1 m/s = 2.24 mph = 3.28 ft/s

Mass and energy
1 u = 1.661×10^{-27} kg
1 cal = 4.19 J
1 eV = 1.60×10^{-19} J

Time
1 day = 86,400 s
1 year = 3.16×10^{7} s

Force
1 lb = 4.45 N

Pressure
1 atm = 101.3 kPa = 760 mm Hg
1 atm = 14.7 lb/in^2

Rotation
1 rad = $180°/\pi$ = 57.3°
1 rev = 360° = 2π rad
1 rev/s = 60 rpm

Greek Letters Used in Physics

Alpha		α	Nu		ν
Beta		β	Pi		π
Gamma	Γ	γ	Rho		ρ
Delta	Δ	δ	Sigma	Σ	σ
Epsilon		ϵ	Tau		τ
Eta		η	Phi	Φ	ϕ
Theta	Θ	θ	Psi		ψ
Lambda		λ	Omega	Ω	ω
Mu		μ			

Mathematical Approximations

Binomial approximation:
$(1+x)^n \approx 1 + nx$ if $x \ll 1$
Small-angle approximation:
$\sin\theta \approx \tan\theta \approx \theta$ and $\cos\theta \approx 1$ if $\theta \ll 1$ radian

Table of Problem-Solving Approaches

Table of Synthesis Boxes

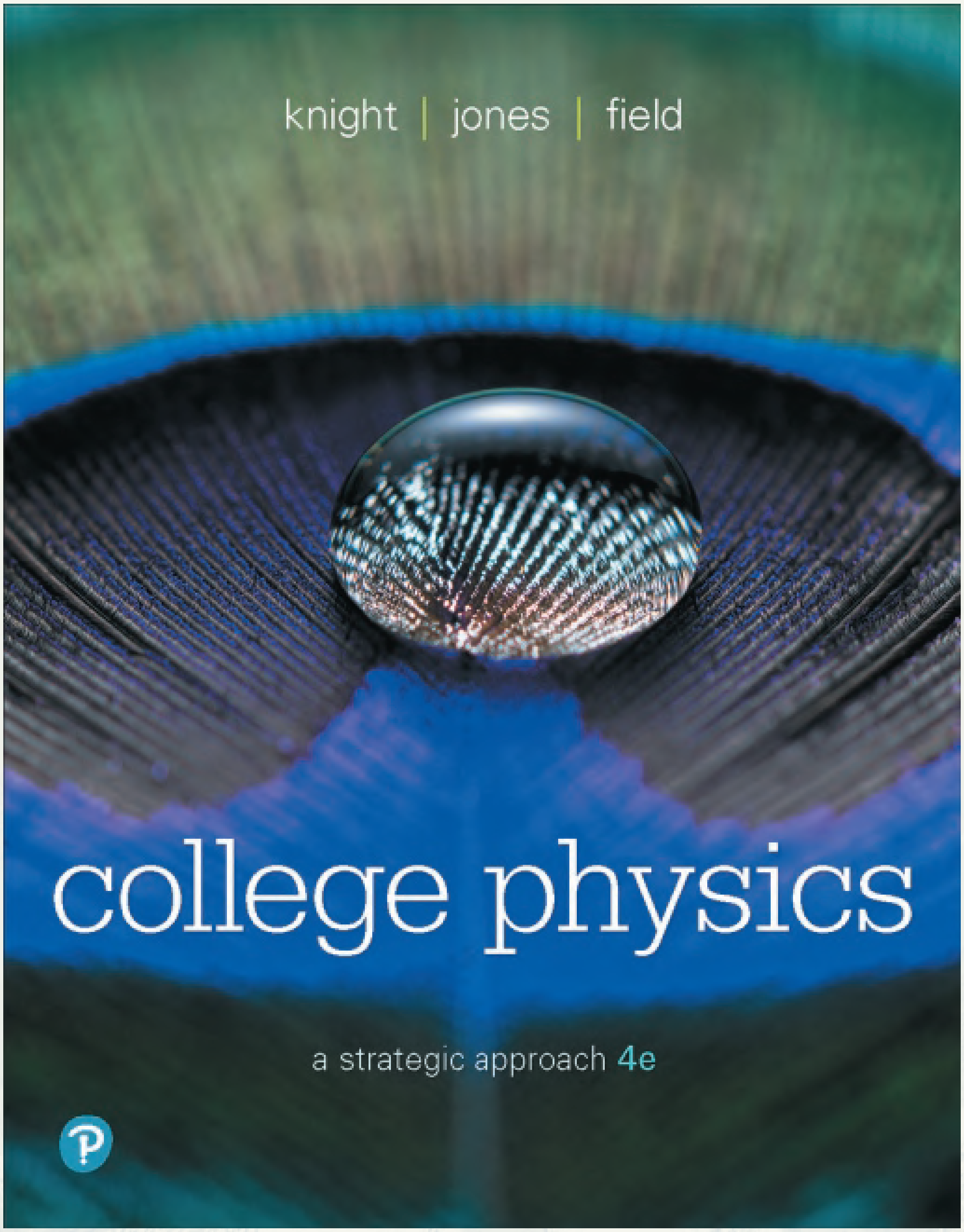
Table of Math Relationships

Note for users of the two-volume edition:
Volume 1 (pp. 1–583)
includes Chapters 1–16.
Volume 2 (pp. 584–1093)
includes Chapters 17–30.

Brief Contents

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.

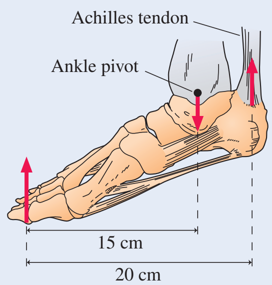
NEW! Topics of interest to life science students, such as the nature of the drag force at different scales and qualitative and quantitative descriptions of diffusion, provide current coverage of relevant topics based on the evolving consensus in the introductory physics for the life sciences community.

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

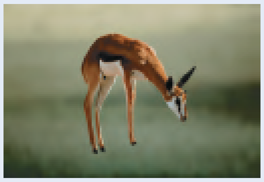
Let's take your foot as the object of interest. When you stand on tiptoe, your foot pivots about your ankle. As shown in FIGURE 8.27, the forces on one foot are an upward force on your toes from the floor, a downward force on your ankle from the lower leg bone, and an upward force on the heel of your 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.

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

8. || 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?

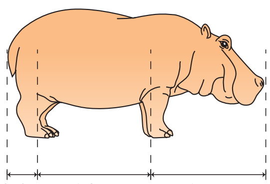


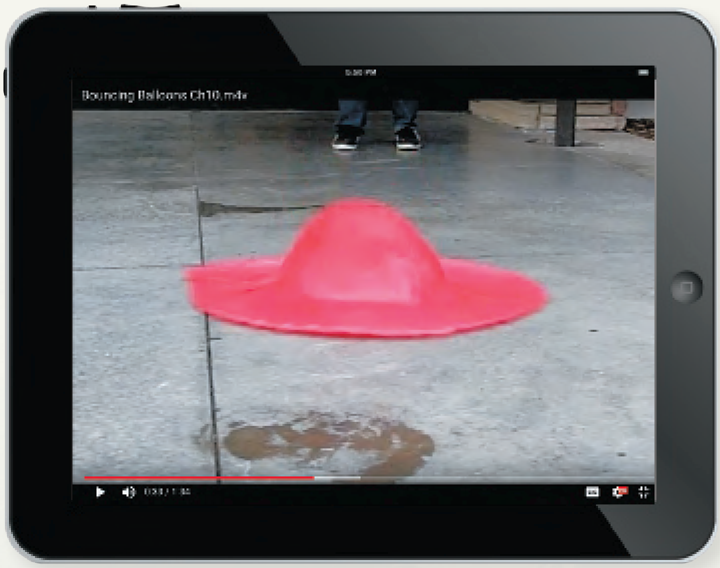
FIGURE P8.8

NEW! 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.

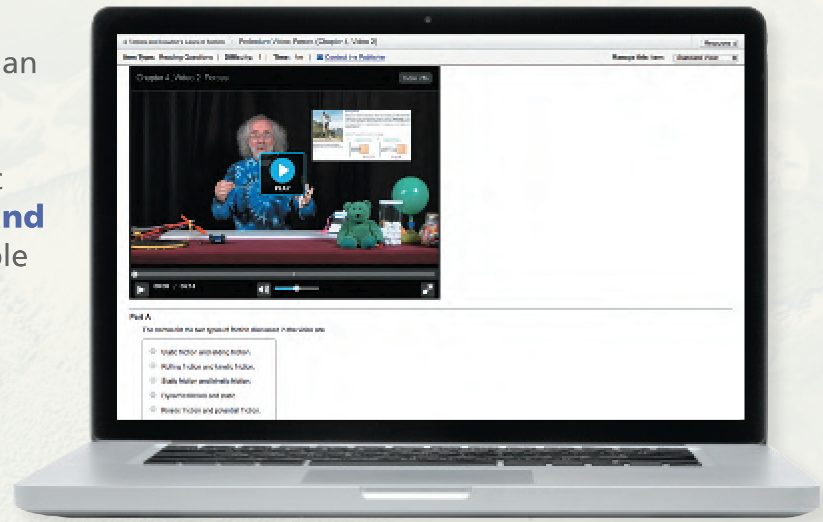
Learning Objectives After studying this chapter, you should be able to:

- 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



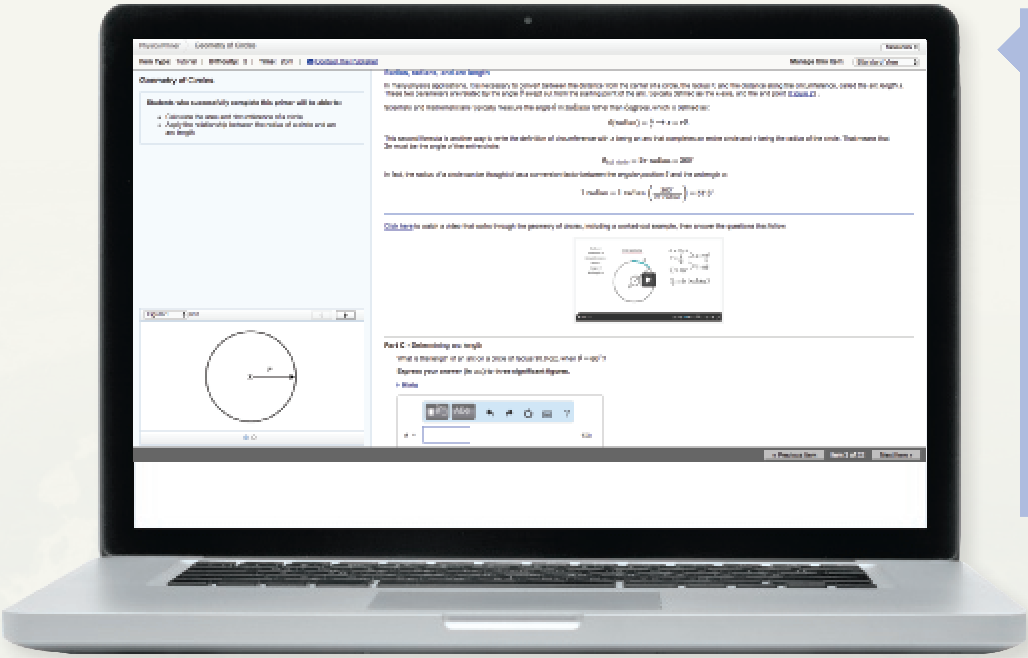
NEW! What the Physics? Videos bring relatable content to engage students with what they are learning and promote curiosity for natural phenomena. These short videos present visually stimulating physical phenomena, pause throughout to address misconceptions, and ask conceptual questions about the physics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



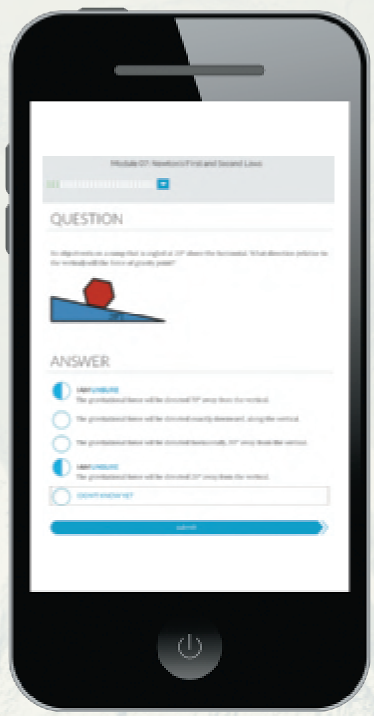
Prelecture Videos, presented by co-author Brian Jones, expand on the Chapter Previews, giving context, examples, and a chance for students to practice the concepts they are studying via short multiple-choice questions. **NEW! Qualitative and Quantitative prelecture videos** now available with assessment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

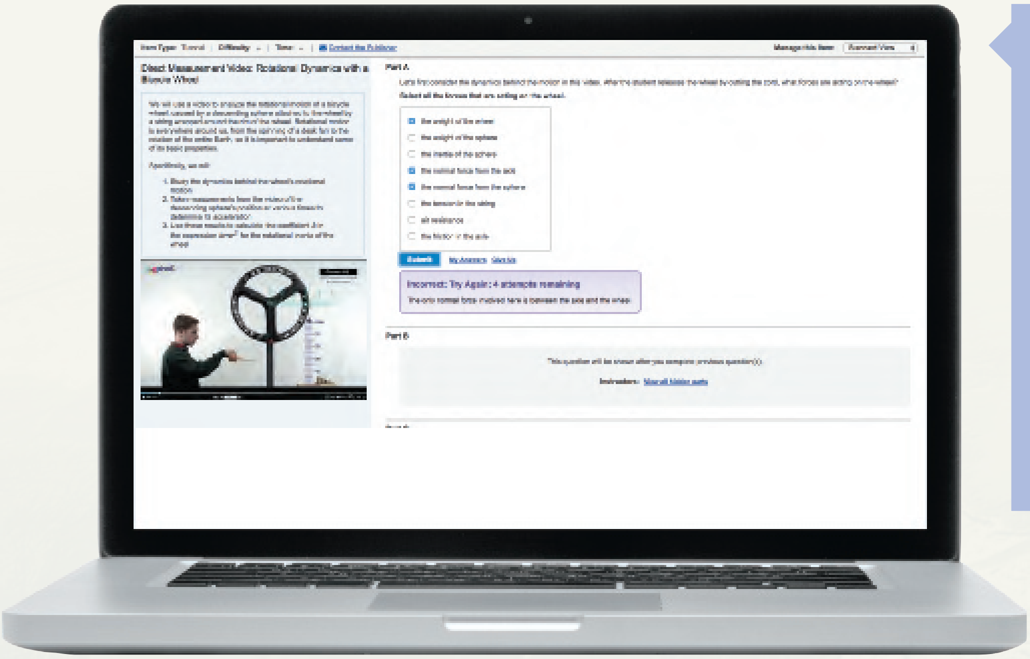


NEW! The Physics Primer relies on videos, hints, and feedback to refresh students' math skills in the context of physics and prepare them for success in the course. These tutorials can be assigned before the course begins as well as throughout the course. They ensure students practice and maintain their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

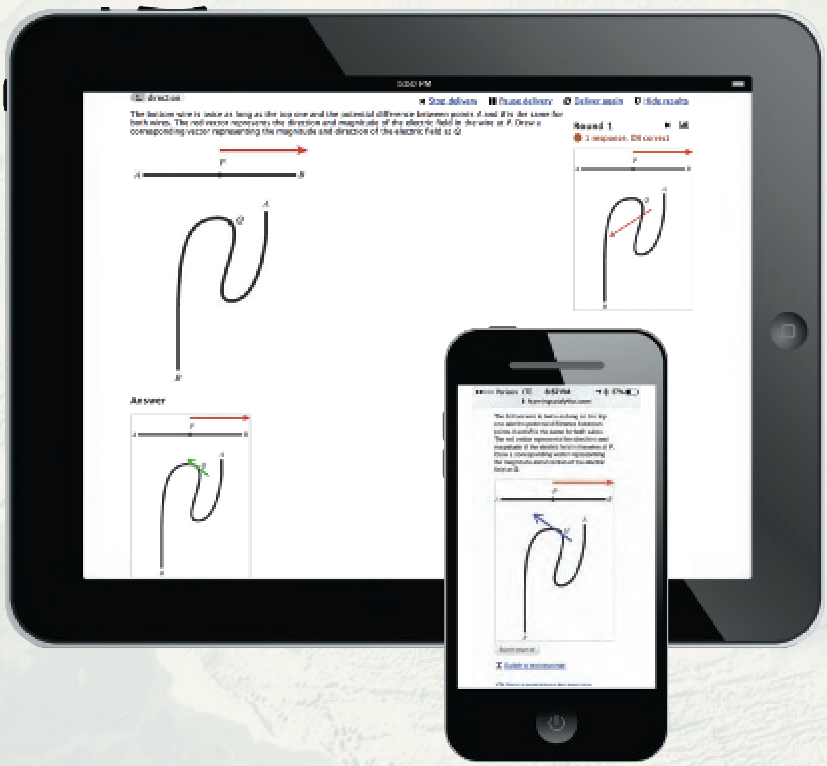
Enhance students' understanding when



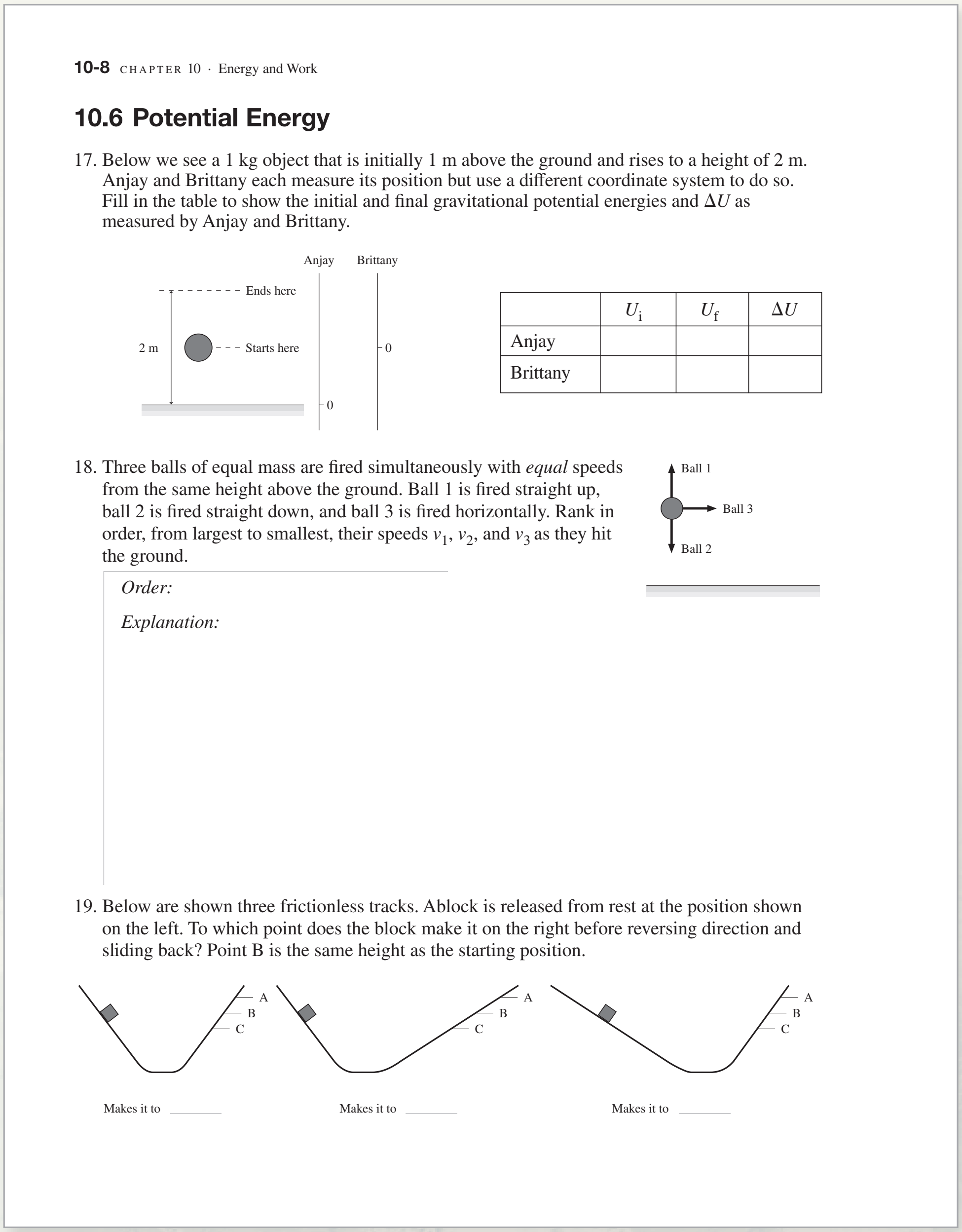
NEW! Direct Measurement Videos are short videos that show real situations of physical phenomena. Grids, rulers, and frame counters appear as overlays, helping students to make precise measurements of quantities such as position and time. Students then apply these quantities along with physics concepts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



they apply what they've learned



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.

	U_i	U_f	ΔU
Anjay			
Brittany			

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:

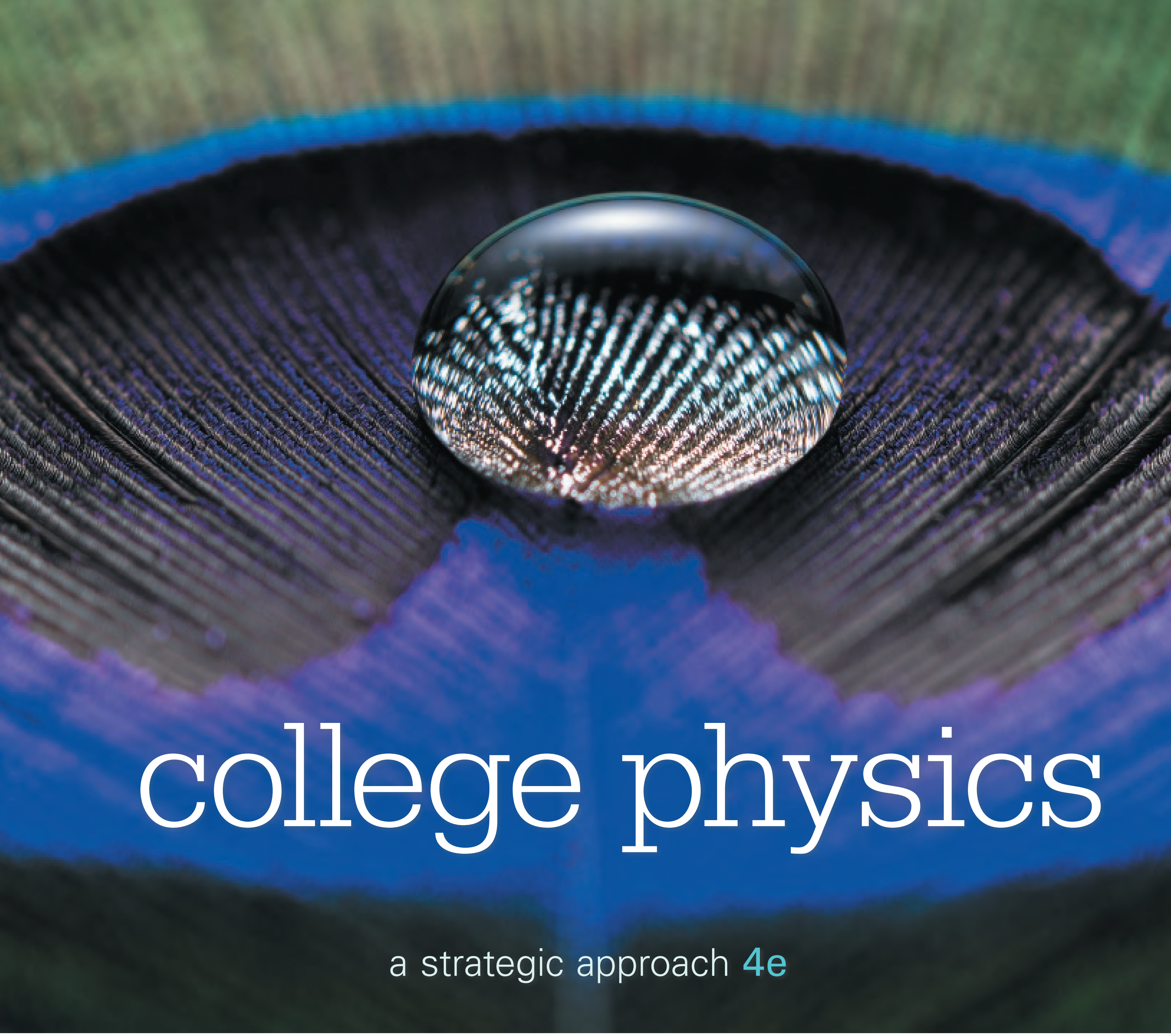
19. Below are shown three frictionless tracks. Ablock is released from rest at the position shown on the left. To which point does the block make it on the right before reversing direction and sliding back? Point B is the same height as the starting position.

Makes it to ______ Makes it to ______ 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 and as pre-built, customizable assignments.



college physics

a strategic approach 4e

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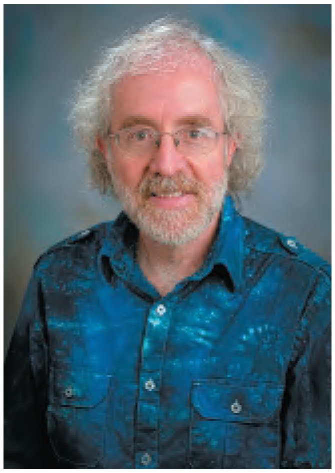
1 19

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.

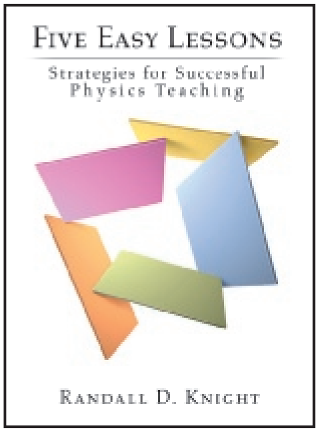
Preface to the Instructor

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*. Please request a copy from your local Pearson sales representative if it is of interest to you (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 a 30-chapter text intended for use in a two-semester course. The textbook 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.

- **Complete edition,** with Mastering™ Physics and Student Workbook (ISBN 978-0-134-64149-2): Chapters 1–30.
- **Books a la Carte edition,** with Mastering™ Physics and Student Workbook (ISBN 978-0-134-64414-1)
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Split your text the way you split your course! Log on to www.pearsonhighered.com/collections/educator-features.html and create your own splits of *College Physics: A Strategic Approach,* 4e, including *your* choice of chapters.

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).

Supplement	Print	Online	Instructor or Student Supplement	Description
Mastering Physics with Pearson eText (ISBN 0134671023)		✓	Instructor and Student Supplement	This product features all of 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.
Instructor's Solutions Manual (ISBN 0134796829)		✓	Instructor Supplement	This comprehensive solutions manual contains complete solutions to all end-of-chapter questions and problems.
TestGen Test Bank (ISBN 0134702409)		✓	Instructor Supplement	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.
Instructor's Resource Materials	✓	✓	Instructor Supplement	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.
Student's Workbook Standard (CH1–30) (ISBN 0134609891X) Volume 1 (CH1–16) (ISBN 0134724828) Volume 2 (CH17–30) (ISBN 0134724801)	✓		Student Supplement	For a more detailed description of the *Student's Workbook,* see page ix.
Student's Solutions Manual Volume 1 (CH1–16) (ISBN 0134704193) Volume 2 (CH17–30) (ISBN 0134724798)	✓		Student Supplement	These solutions manuals contain detailed solutions to all of the odd-numbered end-of-chapter problems from the textbook.
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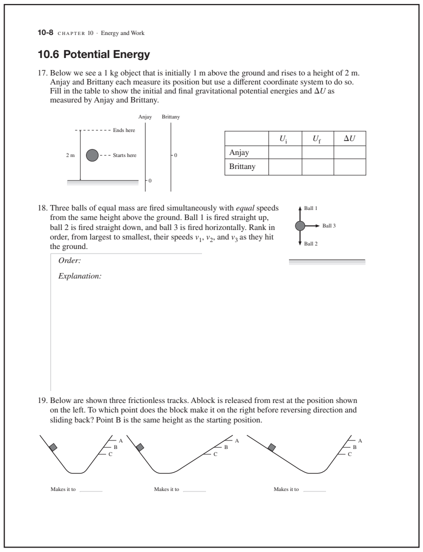
The Student Workbook


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.

	U_i	U_f	ΔU
Anjay			
Brittany			

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. Ablock 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.

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 assigned homework. More information about effective use of the *Student Workbook* can be found in the *Instructor's Guide* in the Ready-to-Go modules.

Available versions: Standard Edition (ISBN 978-0-134-60989-8): Chapters 1-30, Volume 1 (ISBN 978-0-134-72482-9): Chapters 1–16, and Volume 2 (978-0-134-72480-5): Chapters 17–30.

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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.

Studying for and Taking the MCAT Exam

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.

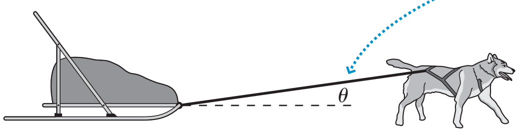


Figure 1

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.

FIGURE MCAT-EXAM.1 Interpreting a passage.

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 $K = \frac{1}{2}mv^2$. 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 Δt is $\Delta y = -\frac{1}{2}gt^2$. The time to fall 1.2 m is $\Delta t = \sqrt{2(1.2\text{ m})/g}$. Rather than complete this calculation, we estimate the results as follows: $\Delta t = \sqrt{2.4/9.8} \approx \sqrt{1/4} = 1/2 = 0.5\text{s}$. 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 3×10^{-19} 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.

Translating

Look at the questions and think about the physics principles that apply, how they connect to concepts you know and understand.

Tips

- Numerical choices are presented in order; that's the usual practice on the test. Estimate the size of the answer, and think about where it falls.
- For questions with sentences as choices, decide on the solution before you look at the choices; this will save time reading.

Reasoning

Think about the question and the range of possible answers, and converge to a solution with as few steps as possible—time is limited!

This is a question about the size of the friction force. You are told that it takes a force that's about 1/6 of the sled's weight to pull it forward on snow. You can estimate the friction coefficient from this information.

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

For an object on level ground, the normal force equals the weight force. If the sled is moving at a constant speed, the pulling force equals the friction force. This implies that $\mu = f_k/n = f_{pull}/w = 1/6$. Two of the answer choices convert easily to fractions: 0.25 = 1/4; 0.05 = 1/20. 1/6 is between these, so C must be our choice. (Indeed, 1/6 = 0.167, so 0.15 is pretty close.)

If the speed is constant, there is no net force. We are told that the pulling force is the horizontal component of the tension force, not the tension force itself. Because there is no net force, this horizontal component is equal to the friction force, which is directed backward. So this is really a question about the friction force.

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.

A vertical component of the tension force will reduce the normal force, reducing the friction force—and thus the pulling force.

We assume that the output power is the same for the two cases—this is implied in the passage.

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

Doubling the weight doubles the normal force, which doubles the friction force. This will double the necessary pulling force as well. Given the expression for power given in the passage, this means the maximum speed will be halved.

This is a question about energy transformation. For such questions, think about changes. What forms of energy are *changing*? We know that thermal energy is part of the picture because some of the chemical energy is converted to thermal energy in the dog's body.

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

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.

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.

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

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.

The passage tells us that the dog uses 400 J of metabolic energy to do 100 J of work. 300 J, or 75%, must be exhausted to the environment. We can assume the same efficiency here.

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

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

FIGURE MCAT-EXAM.2 Answering the questions for the passage of Figure MCAT-EXAM.1.

Real-World Applications

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

Part II Summary

Chapter 12

Chapter 13

Part III Summary

Chapter 14

Chapter 15

Chapter 16

Part IV Summary

Chapter 17

Chapter 18

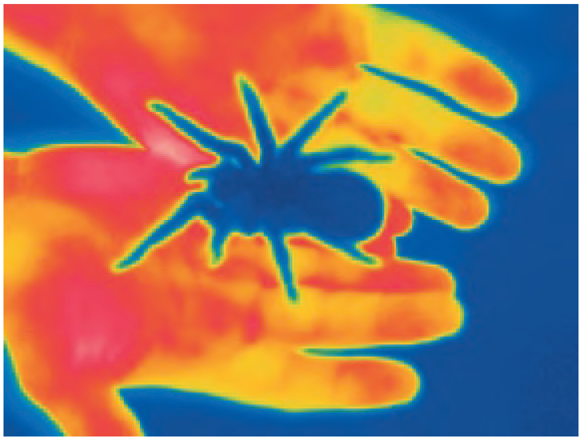
Chapter 19

Part V Summary

Chapter 20

Detailed Contents

PART II Conservation Laws



PART VII Modern Physics

PART 1

Force and Motion

The cheetah is the fastest land animal, able to run at speeds exceeding 60 miles per hour. Nonetheless, the rabbit has an advantage in this chase. It can *change* its motion more quickly and will likely escape. How can you tell, by looking at the picture, that the cheetah is changing its motion?

OVERVIEW

The Science of Physics

Physics is the foundational science that underlies biology, chemistry, earth sciences, and all other fields that attempt to understand our natural world. Physicists couple careful experimentation with deep theoretical insights to build powerful and predictive models of how the world works. A key aspect of physics is that it is a *unifying* discipline: A relatively small number of key concepts can explain a vast array of natural phenomena. In this text, we have organized the chapters into parts according to seven of these unifying principles. Each of the seven parts of this text opens with an overview that gives you a look ahead, a glimpse of where your journey will take you in the next few chapters. It's easy to lose sight of the big picture while you're busy negotiating the terrain of each chapter. In Part I, the big picture is, in a word, *change*.

Why Things Change

Simple observations of the world around you show that most things change. Some changes, such as aging, are biological. Others, such as the burning of gasoline in your car, are chemical. We will look at changes that involve *motion* of one form or another—running and jumping, throwing balls, lifting weights.

There are two big questions we must tackle to study how things change by moving:

- **How do we describe motion?** How should we measure or characterize the motion if we want to analyze it mathematically?
- **How do we explain motion?** Why do objects have the particular motion they do? Why, when you toss a ball upward, does it go up and then come back down rather than keep going up? What are the "laws of nature" that allow us to predict an object's motion?

Two key concepts that will help answer these questions are *force* (the "cause") and *acceleration* (the "effect"). Our basic tools will be three laws of motion worked out by Isaac Newton. Newton's laws relate force to acceleration, and we will use them to explain and explore a wide range of problems. As we learn to solve problems dealing with motion, we will learn basic techniques that we can apply in all the parts of this text.

Simplifying Models

Another key aspect of physics is the importance of models. Suppose we want to analyze a ball moving through the air. Is it necessary to analyze the way the atoms in the ball are connected? Or the details of how the ball is spinning? Or the small drag force it experiences as it moves? These are interesting questions, of course. But if our task is to understand the motion of the ball, we need to simplify!

We can conduct a perfectly fine analysis of the ball's motion if we treat the ball as a single particle moving through the air. This is a *model* of the situation. A model is a simplified description of reality that is used to reduce the complexity of a problem so it can be analyzed and understood. Model building is a major part of the strategy that we will develop for solving problems throughout the text. Learning how to simplify a situation is the essence of successful modeling—and successful problem solving.

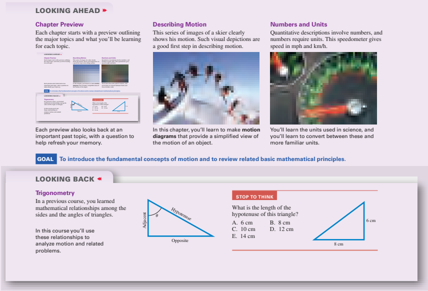
1 Representing Motion

As this falcon moves in a graceful arc through the air, the direction of its motion and the distance between each of its positions and the next are constantly changing. What language should we use to describe this motion?

LOOKING AHEAD ➤

Chapter Preview

Each chapter starts with a preview outlining the major topics and what you'll be learning for each topic.



Each preview also looks back at an important past topic, with a question to help refresh your memory.

Describing Motion

This series of images of a skier clearly shows his motion. Such visual depictions are a good first step in describing motion.

In this chapter, you'll learn to make **motion diagrams** that provide a simplified view of the motion of an object.

Numbers and Units

Quantitative descriptions involve numbers, and numbers require units. This speedometer gives speed in mph and km/h.

You'll learn the units used in science, and you'll learn to convert between these and more familiar units.

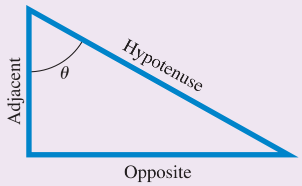
GOAL To introduce the fundamental concepts of motion and to review related basic mathematical principles.

LOOKING BACK ◀

Trigonometry

In a previous course, you learned mathematical relationships among the sides and the angles of triangles.

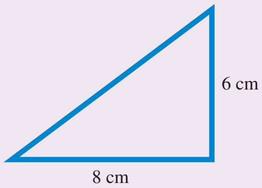
In this course you'll use these relationships to analyze motion and related problems.



STOP TO THINK

What is the length of the hypotenuse of this triangle?

A. 6 cm B. 8 cm
C. 10 cm D. 12 cm
E. 14 cm



1.1 Motion: A First Look

Motion is a theme that will appear in one form or another throughout this entire text. You have a well-developed intuition about motion based on your experiences, but we'll find that some of the most important aspects of motion can be rather subtle. We need to develop some tools to help us explain and understand motion, so rather than jumping immediately into a lot of mathematics and calculations, this first chapter focuses on *visualizing* motion and becoming familiar with the *concepts* needed to describe a moving object.

One key difference between physics and other sciences is how we set up and solve problems. We'll often use a two-step process to solve motion problems. The first step is to develop a simplified *representation* of the motion so that key elements stand out. For example, the photo of the falcon at the start of the chapter allows us to observe its position at many successive times. We will begin our study of motion by considering this sort of picture. The second step is to analyze the motion with the language of mathematics. The process of putting numbers on nature is often the most challenging aspect of the problems you will solve. In this chapter, we will explore the steps in this process as we introduce the basic concepts of motion.

Types of Motion

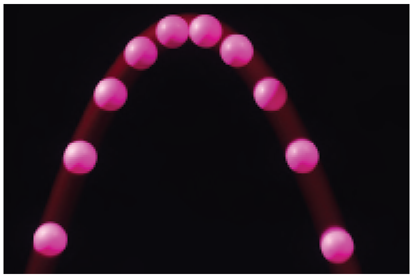
As a starting point, let's define **motion** as the change of an object's position or orientation with time. Examples of motion are easy to list. Bicycles, baseballs, cars, airplanes, and rockets are all objects that move. The path along which an object moves, which might be a straight line or might be curved, is called the object's **trajectory.**

FIGURE 1.1 shows four basic types of motion that we will study in this text. In this chapter, we will focus on the first type of motion in the figure, motion along a straight line, or *straight-line motion*. In later chapters, we will learn about *circular motion*, which is the motion of an object along a circular path; *projectile motion*, the motion of an object through the air; and *rotational motion*, the spinning of an object about an axis.

FIGURE 1.1 Four basic types of motion.

Straight-line motion

Circular motion



Projectile motion

Rotational motion

Making a Motion Diagram

An easy way to study motion is to record a video of a moving object with a stationary camera. A video camera takes images at a fixed rate, typically 30 images every second. Each separate image is called a *frame*. As an example, FIGURE 1.2 shows several frames from a video of a car going past, with the camera in a fixed position. Not surprisingly, the car is in a different position in each frame.

FIGURE 1.2 Several frames from the video of a car.

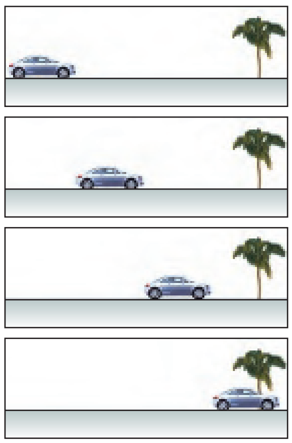
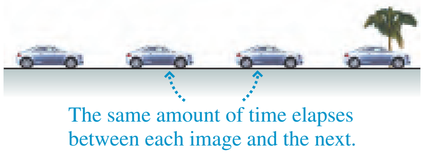


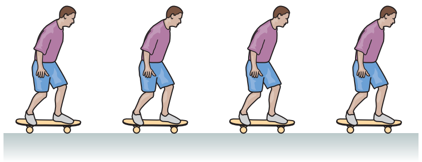
FIGURE 1.3 A motion diagram of the car shows all the frames simultaneously.



Suppose we now edit the video by layering the frames on top of each other. We end up with the picture in **FIGURE 1.3**. This composite image, showing an object's positions at several *equally spaced instants of time,* is called a **motion diagram.** As simple as motion diagrams seem, they will turn out to be powerful tools for analyzing motion.

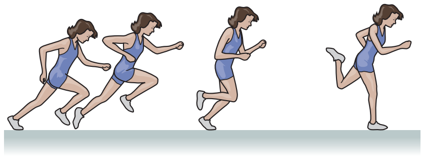
Now let's take our camera out into the world and make some motion diagrams. The following table illustrates how a motion diagram shows important features of different kinds of motion.

Examples of motion diagrams



Images that are *equally spaced* indicate an object moving with *constant speed*.

A skateboarder rolling down the sidewalk.



An *increasing distance* between the images shows that the object is *speeding up*.

A sprinter starting the 100 meter dash.

A *decreasing distance* between the images shows that the object is *slowing down*.

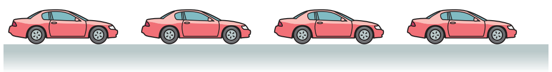
A car stopping for a red light.

A more complex motion diagram shows changes in speed and direction.

A basketball free throw.

We have defined several concepts (constant speed, speeding up, and slowing down) in terms of how the moving object appears in a motion diagram. These are called **operational definitions,** meaning that the concepts are defined in terms of a particular procedure or operation. For example, we could answer the question Is the airplane speeding up? by checking whether the images in the plane's motion diagram are getting farther apart. Many of the concepts in physics will be introduced as operational definitions. This reminds us that physics is an experimental science.

STOP TO THINK 1.1 Which car is going faster, A or B? Assume there are equal intervals of time between the frames of both videos.



Car A

Car B

NOTE ▶ Each chapter in this text has several *Stop to Think* questions. These questions are designed to see if you've understood the basic ideas that have just been presented. The answers are given at the end of the chapter, but you should make a serious effort to think about these questions before turning to the answers. ◀

1.2 Models and Modeling

The real world is messy and complicated. Our goal in studying physics is to brush aside many of the real-world details in order to discern patterns that occur over and over. For example, a swinging pendulum, a vibrating guitar string, a sound wave, and jiggling atoms in a crystal are all very different—yet they share a common core characteristic: Each is an example of an *oscillating system*, something that moves back and forth around an equilibrium position. If we focus on understanding a very simple oscillating system, such as a block (generically, a "mass") attached to a spring, we'll automatically understand quite a bit about the many real-world examples of oscillations.

Stripping away the details to focus on essential features is a process called *modeling*. A **model** is a highly simplified picture of reality, but one that still captures the essence of what we want to study. Thus a mass attached to a spring is a simple but realistic model of many oscillating systems.

Models allow us to make sense of complex situations by providing a framework for thinking about them. One could go so far as to say that developing and testing models is at the heart of the scientific process. Albert Einstein once said, "Physics should be as simple as possible—but not simpler." We want to find the simplest model that allows us to understand the phenomenon we're studying, but we can't make the model so simple that key aspects of the phenomenon get lost.

We'll develop and use many models throughout this text; they'll be one of our most important thinking tools. These models will be of two types:

- *Descriptive models:* What are the essential characteristics and properties of a phenomenon? How do we describe it in the simplest possible terms? For example, the mass-on-a-spring model of an oscillating system is a descriptive model.
- *Explanatory models:* Why do things happen as they do? Explanatory models, based on the laws of physics, have predictive power. They allow us to test—against experimental data—whether a model provides an adequate explanation of our observations. For example, the *charge model* that we will introduce in Chapter 20 helps us explain and predict a wide range of experimental outcomes related to electric forces.

When we solve physics problems, one of the most important steps is choosing an appropriate model for the system we are studying. In the worked examples in this text, in the first "Strategize" step, we'll point out the model being used, when appropriate.

The Particle Model

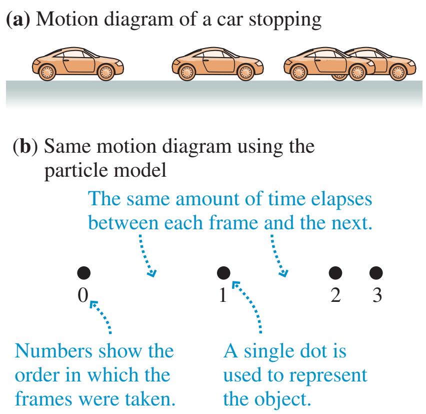
For many objects, the motion of the object *as a whole* is not influenced by the details of the object's size and shape. To describe the object's motion, all we really need to keep track of is the motion of a single point: You could imagine looking at the motion of a dot painted on the side of the object.

In fact, for the purposes of analyzing the motion, we can often consider the object *as if* it were just a single point. We can also treat the object *as if* all of its mass were concentrated into this single point. An object that can be represented as a mass at a single point in space is called a **particle.**

If we treat an object as a particle, we can represent the object in each frame of a motion diagram as a simple dot. **FIGURE 1.4** shows how much simpler motion diagrams appear when the object is represented as a particle. Note that the dots have been numbered 0, 1, 2, . . . to tell the sequence in which the frames were exposed. These diagrams still convey a complete understanding of the object's motion.

In representing the car in Figure 1.4 as a particle, we have discarded many of the details of the car, such as the shape of its body and the motion of its wheels, which are unimportant in understanding its overall motion. In other words, we have developed a model for moving objects, the **particle model,** that allows us to see

FIGURE 1.4 Simplifying a motion diagram using the particle model.



A video to support a section's topic is embedded in the eText.

Video Figure 1.4

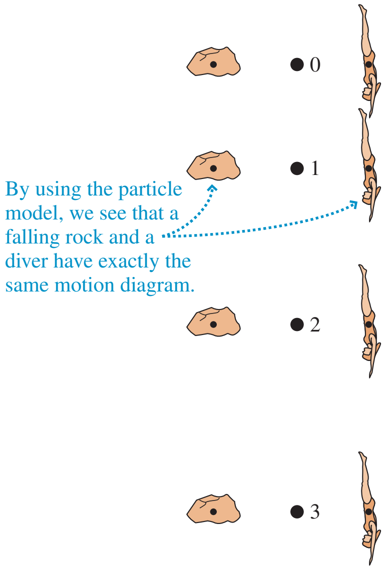
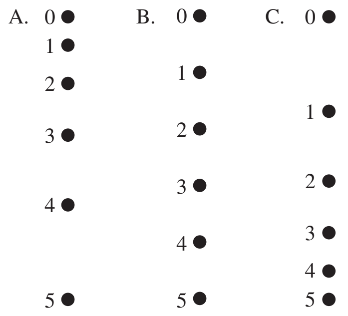


FIGURE 1.5 The particle model for two falling objects.

connections that are very important but that are obscured or lost by examining all the parts of an extended, real object. Consider the motion of the rock and the diver shown in **FIGURE 1.5.** These two very different objects have exactly the same motion diagram. As we will see, all objects falling under the influence of gravity move in exactly the same manner if no other forces act. The simplification of the particle model has revealed something about the physics that underlies both of these situations.

STOP TO THINK 1.2 Three motion diagrams are shown. Which is a dust particle settling to the floor at constant speed, which is a ball dropped from the roof of a building, and which is a descending rocket slowing to make a soft landing on Mars?

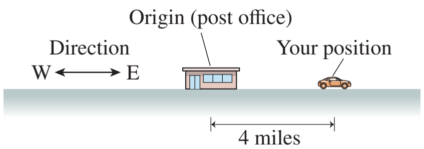


1.3 Position and Time: Putting Numbers on Nature

To develop our understanding of motion further, we need to be able to make quantitative measurements: We need to use numbers. As we analyze a motion diagram, it is useful to know where the object is (its *position*) and when the object was at that position (the *time*). We'll start by considering the motion of an object that can move only along a straight line. Examples of this **one-dimensional** or "1-D" motion are a car moving along a long, straight road; an airplane taxiing down a runway; and an elevator moving up and down a shaft.

Position and Coordinate Systems

FIGURE 1.6 Describing your position.



This gauge's vertical scale measures the depth of snow when it falls. It has a natural origin at the level of the road.

Suppose you are driving along a long, straight country road, as in **FIGURE 1.6,** and your friend calls and asks where you are. You might reply that you are 4 miles east of the post office, and your friend would then know just where you were. Your location at a particular instant in time (when your friend phoned) is called your **position.** Notice that to know your position along the road, your friend needed three pieces of information. First, you had to give her a reference point (the post office) from which all distances are to be measured. We call this fixed reference point the **origin.** Second, she needed to know how far you were from that reference point or origin—in this case, 4 miles. Finally, she needed to know which side of the origin you were on: You could be 4 miles to the west of it or 4 miles to the east.

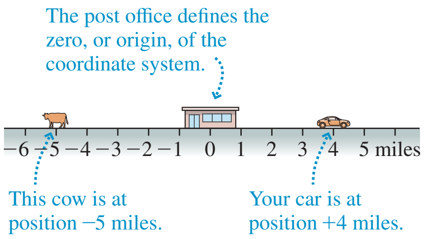
We will need these same three pieces of information in order to specify any object's position along a line. We first choose our origin, from which we measure the distance to the object. The position of the origin is arbitrary, and we are free to place it where we like. Usually, however, there are certain points (such as the well-known post office) that are more convenient choices than others.

In order to specify how far our object is from the origin, we lay down an imaginary axis along the line of the object's motion. Like a ruler, this axis is marked off in equally spaced divisions of distance, perhaps in inches, meters, or miles, depending on the problem at hand. We place the zero mark of this ruler at the origin, allowing us to locate the position of our object by reading the ruler mark where the object is.

Finally, we need to be able to specify which side of the origin our object is on. To do this, we imagine the axis extending from one side of the origin with increasing positive markings; on the other side, the axis is marked with increasing *negative* numbers. By reporting the position as either a positive or a negative number, we know on what side of the origin the object is.

These elements—an origin and an axis marked in both the positive and negative directions—can be used to unambiguously locate the position of an object. We call this a **coordinate system.** We will use coordinate systems throughout this text, and we will soon develop coordinate systems that can be used to describe the positions of objects moving in more complex ways than just along a line. FIGURE 1.7 shows a coordinate system that we can use to locate various objects along the country road discussed earlier.

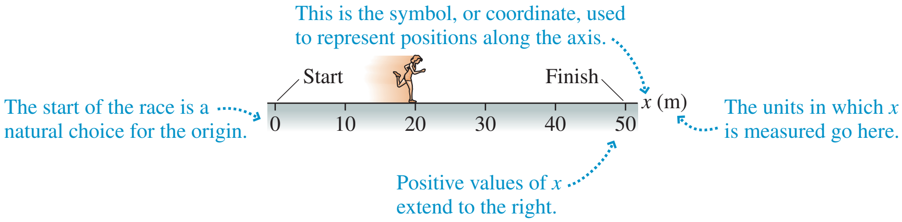
FIGURE 1.7 The coordinate system used to describe objects along a country road.



Although our coordinate system works well for describing the positions of objects located along the axis, our notation is somewhat cumbersome because we keep needing to say things like "the car is at position +4 miles." A better notation, and one that will become particularly important when we study motion in two dimensions, is to use a symbol such as x or y to represent the position along the axis. Then we can say "the cow is at $x = -5$ miles." The symbol that represents a position along an axis is called a **coordinate.** The introduction of symbols to represent positions (and, later, velocities and accelerations) also allows us to work with these quantities mathematically.

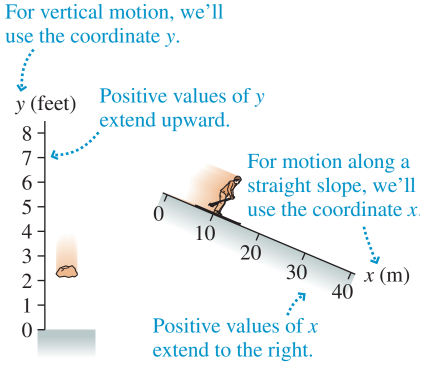
FIGURE 1.8 shows how we would set up a coordinate system for a sprinter running a 50 meter race (we use the standard abbreviation "m" for meters). For horizontal motion like this we usually use the coordinate x to represent the position.

FIGURE 1.8 A coordinate system for a 50 meter race.



Motion along a straight line need not be horizontal. As shown in FIGURE 1.9, a rock falling vertically downward and a skier skiing down a straight slope are also examples of straight-line or one-dimensional motion.

FIGURE 1.9 Examples of one-dimensional motion.



Time

The pictures in Figure 1.9 show the position of an object at just one instant of time. But a full motion diagram represents how an object moves as time progresses. So far, we have labeled the dots in a motion diagram by the numbers 0, 1, 2, . . . to indicate the order in which the frames were taken. But to fully describe the motion, we need to indicate the *time,* as read off a clock or a stopwatch, at which each frame of a video was made. This is important, as we can see from the motion diagram of a stopping car in FIGURE 1.10. If the frames were taken 1 second apart, this motion diagram shows a leisurely stop; if 1/10 of a second apart, it represents a screeching halt.

FIGURE 1.10 Is this a leisurely stop or a screeching halt?

For a complete motion diagram, we thus need to label each frame with its corresponding time (symbol t) as read off a clock. But when should we start the clock? Which frame should be labeled $t = 0$? This choice is much like choosing the origin $x = 0$ of a coordinate system: You can pick any arbitrary point in the motion and label it "$t = 0$ seconds." This is simply the instant you decide to start your clock or stopwatch, so it is the origin of your time coordinate. A video frame labeled "$t = 4$ seconds" means it was taken 4 seconds after you started your clock. We typically choose $t = 0$ to represent the "beginning" of a problem, but the object may have been moving before then.