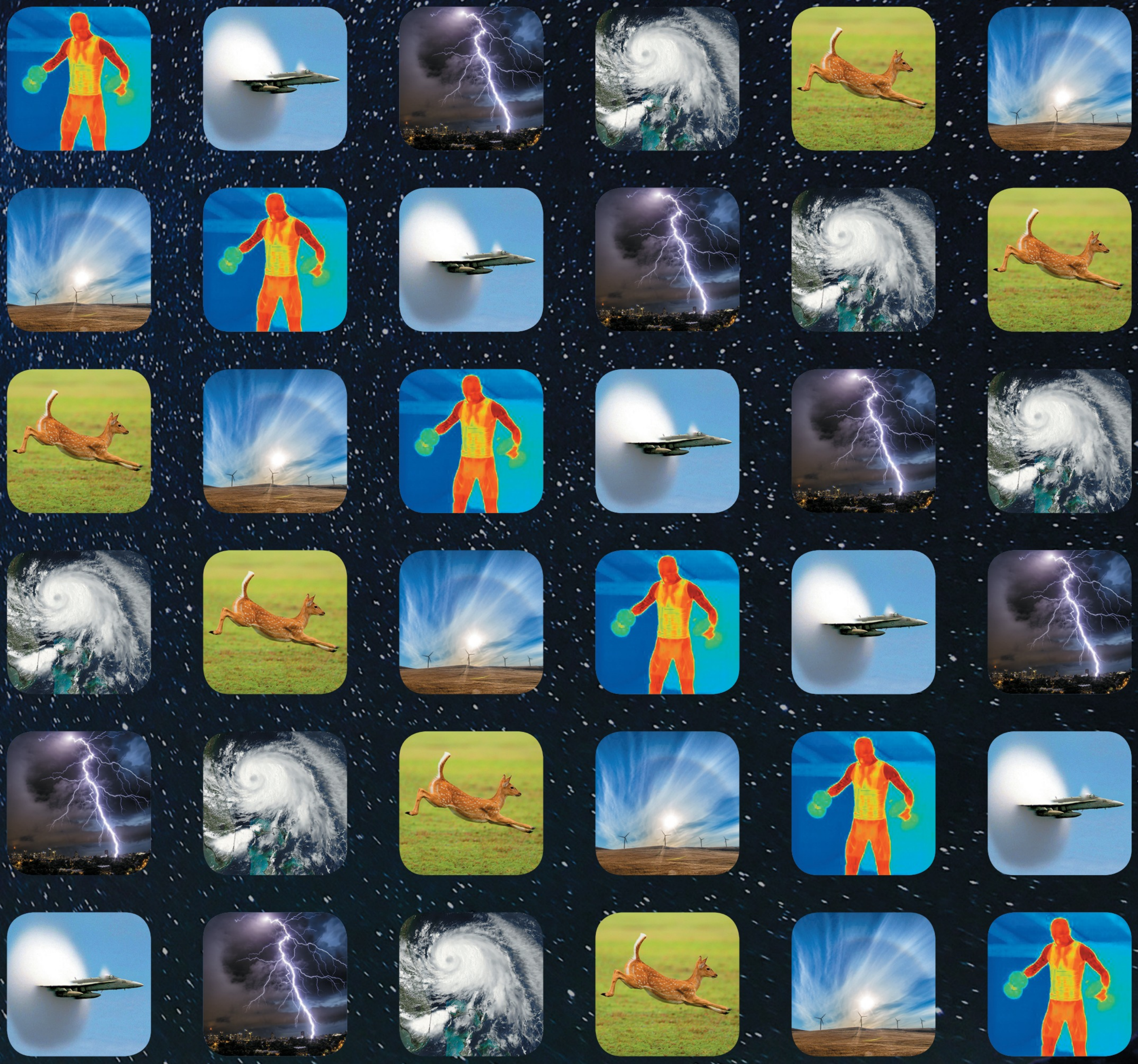
PHYSICS

FIFTH EDITION



JAMES S. WALKER

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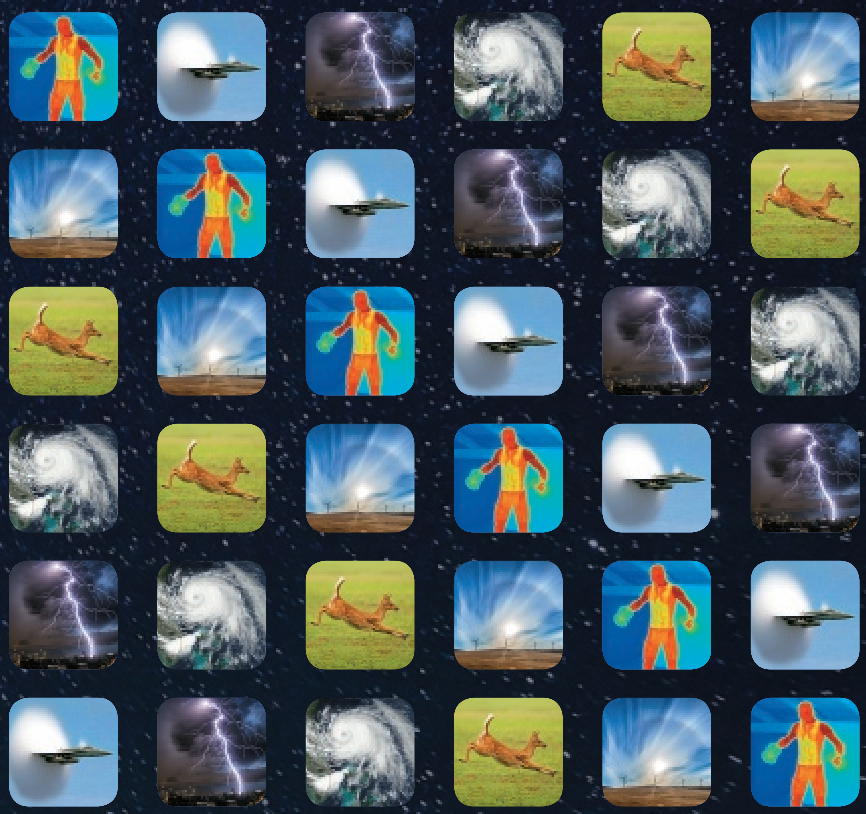
JAMES S. WALKER
Western Washington University



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THIS BOOK IS DEDICATED TO MY PARENTS, IVAN AND JANET WALKER, AND TO MY WIFE, BETSY.

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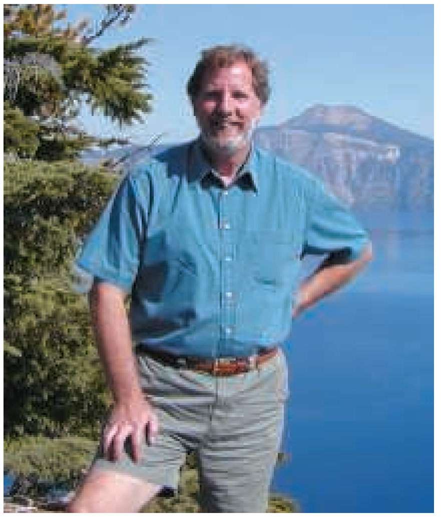
ABOUT THE AUTHOR

JAMES S. WALKER



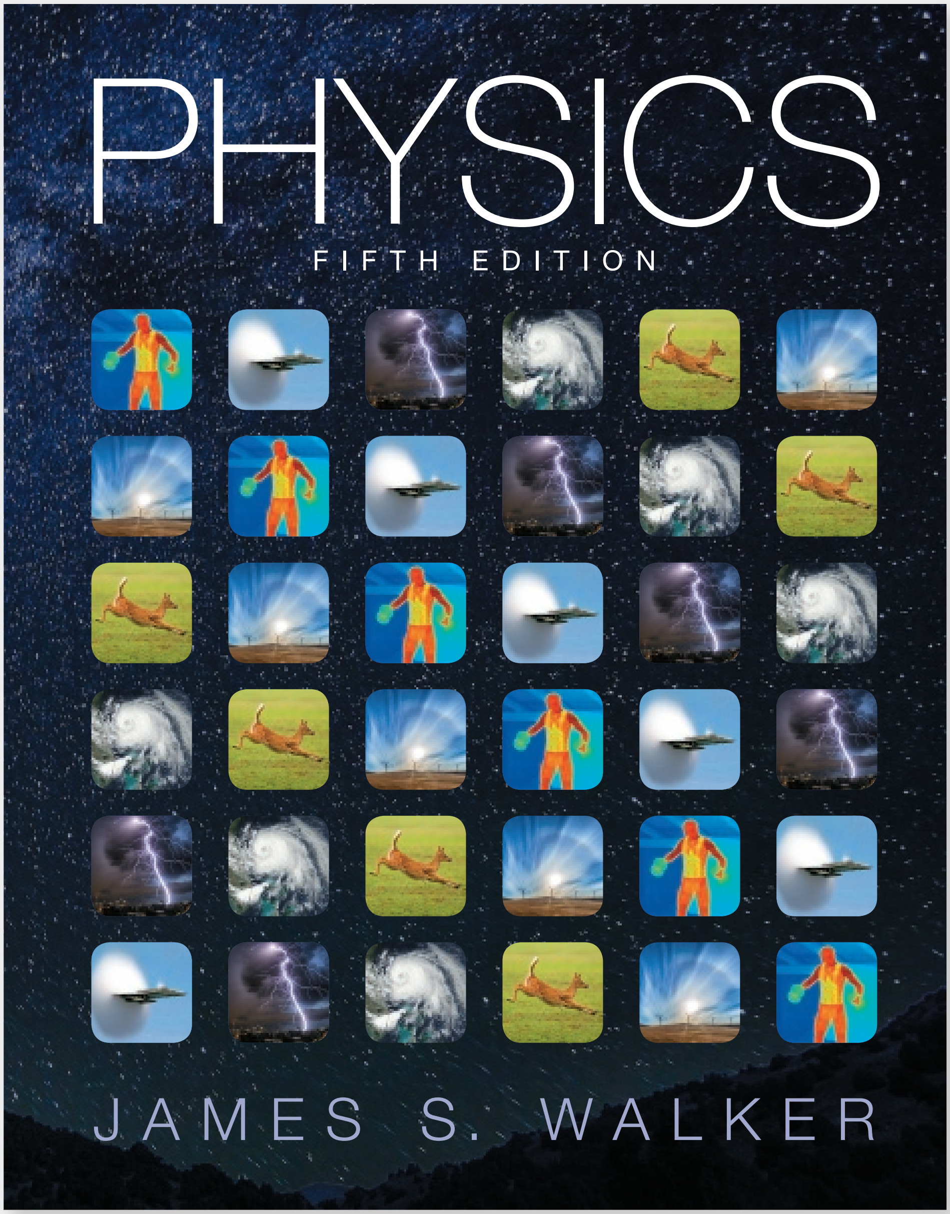
James Walker obtained his Ph.D. in theoretical physics from the University of Washington in 1978. He subsequently served as a post-doc at the University of Pennsylvania, the Massachusetts Institute of Technology, and the University of California at San Diego before joining the physics faculty at Washington State University in 1983. Professor Walker's research interests include statistical mechanics, critical phenomena, and chaos. His many publications on the application of renormalization-group theory to systems ranging from absorbed monolayers to binary-fluid mixtures have appeared in *Physical Review, Physical Review Letters, Physica,* and a host of other publications. He has also participated in observations on the summit of Mauna Kea, looking for evidence of extra-solar planets.

Jim Walker likes to work with students at all levels, from judging elementary school science fairs to writing research papers with graduate students, and has taught introductory physics for many years. Through his enjoyment of this course and his empathy for students, Jim has earned a reputation as an innovative, enthusiastic, and effective teacher. Jim's educational publications include "Reappearing Phases" (*Scientific American*, May 1987) as well as articles in the *American Journal of Physics* and *The Physics Teacher*. In recognition of his contributions to the teaching of physics at Washington State University, Jim was named the Boeing Distinguished Professor of Science and Mathematics Education for 2001–2003.

When he is not writing, conducting research, teaching, or developing new classroom demonstrations and pedagogical materials, Jim enjoys amateur astronomy, eclipse chasing, bird and dragonfly watching, photography, juggling, unicycling, boogie boarding, and kayaking. Jim is also an avid jazz pianist and organist. He has served as ballpark organist for a number of Class A minor league baseball teams, including the Bellingham Mariners, an affiliate of the Seattle Mariners, and the Salem-Keizer Volcanoes, an affiliate of the San Francisco Giants. He can play "Take Me Out to the Ball Game" in his sleep.

BRIEF CONTENTS

An accessible, problem-solving approach to physics, grounded in real-world applications



What's the Big Idea?

James Walker's ***Physics***, Fifth Edition engages students by connecting conceptual and quantitative physics to the world around them, making complex concepts understandable, and helping students build problem-solving skills. New "just in time" learning aids, such as the "Big Ideas," quickly orient students to the overarching principles of each chapter, while new Real-World Physics and Biological Applications expose students to physics they can observe in their own lives. A revised problem-solving pedagogy allows students to build a deep understanding of the relationship between the conceptual and the quantitative.

Ample "just in time" learning aids help students where they need it, when they need it

NEW! BIG IDEAS appear on each chapter-opening page to quickly orient students to the overarching principles of each chapter. Details highlighting key takeaways for students appear in the chapter margins next to where these ideas are introduced in the narrative.

Big Ideas

1 Work is force times distance.

2 Kinetic energy is one-half mass times velocity squared.

3 Power is the rate at which wo

Big Idea 1 Work is force times distance when force and displacement are in the same direction. More generally, work is the component of force in the direction of displacement times the distance.

NEW! PHYSICS IN CONTEXT calls attention to a related or supporting concept covered in a previous chapter ("Physics in Context: Looking Back"); or alerts students to a concept to be covered in a future chapter that relates to what they're reading ("Physics in Context: Looking Ahead").

PHYSICS IN CONTEXT
Looking Back

Conservation of energy, first introduced in Chapter 8, is just as important in rotational motion as it is in linear motion.

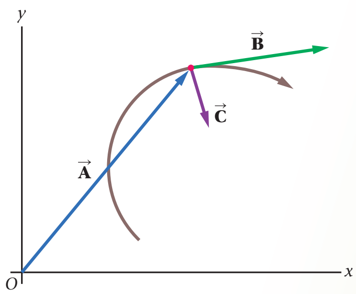
PHYSICS IN CONTEXT
Looking Ahead

In Chapter 5 we will introduce one of the most important concepts in all of physics—force. It is a vector quantity. Other important vector quantities to be introduced in later chapters include linear momentum (Chapter 9), angular momentum (Chapter 11), electric field (Chapter 19), and magnetic field (Chapter 22).

NEW! REAL-WORLD PHYSICS AND BIOLOGICAL APPLICATIONS woven into the text have been updated with fresh topics relevant to today's student. These applications bring abstract physics principles to life with real-life examples from the world around us.

Enhance Your Understanding (Answers given at the end of the chapter)

5. An object moves along the brown path in **FIGURE 3-30** in the direction indicated. Which physical quantity (position, acceleration, velocity) is represented by the following vectors: **(a)** $\vec{\mathbf{A}}$, **(b)** $\vec{\mathbf{B}}$, **(c)** $\vec{\mathbf{C}}$?



▲ **FIGURE 3-30** Enhance Your Understanding 5

Section Review

- Many physical quantities are represented by vectors. Among these are position, displacement, velocity, and acceleration.

NEW! ENHANCE YOUR UNDERSTANDING qualitative multiple-choice and ranking questions appear before each Section Review to give students an opportunity to practice what they've just learned. Answers are listed at the end of the chapter.

NEW! SECTION REVIEWS briefly synthesize the key ideas covered in the preceding section for a quick at-a-glance summary.

Thorough problem-solving instruction and multiple opportunities for practice

The Fifth Edition continues the Walker tradition of providing ample opportunity for students to develop problem-solving skills with a greater variety of example types and more thoroughly stepped out explanations and guidance.

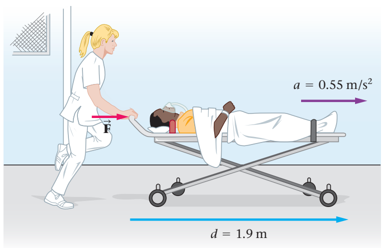
NEW! KNOWNS AND UNKNOWNS

have been added to worked examples to model how scientists think about setting up a problem before they solve it.

EXAMPLE 7-2 HEADING FOR THE ER

An intern pushes an 87-kg patient on an 18-kg gurney, producing an acceleration of $0.55\ \mathrm{m/s^2}$. **(a)** How much work does the intern do in pushing the patient and gurney through a distance of 1.9 m? Assume the gurney moves without friction. **(b)** How far must the intern push the gurney to do 140 J of work?

PICTURE THE PROBLEM
Our sketch shows the physical situation for this problem. Notice that the force exerted by the intern is in the same direction as the displacement of the gurney; therefore, we know that the work is $W = Fd$.



REASONING AND STRATEGY
We are not given the magnitude of the force, F, so we cannot apply Equation 7-1 ($W = Fd$) directly. However, we are given the mass and acceleration of the patient and gurney, and from them we can calculate the force with $F = ma$. The work done by the intern is then $W = Fd$, where $d = 1.9$ m.

Known Mass of patient, 87 kg; mass of gurney, 18 kg; acceleration, $a = 0.55\ \mathrm{m/s^2}$; **(a)** pushing distance, $d = 1.9$ m; **(b)** work, $W = 140$ J.
Unknown **(a)** Work done, W = ? **(b)** Pushing distance, d = ?

SOLUTION

Part (a)

1. First, find the force F exerted by the intern: $F = ma = (87\ \mathrm{kg} + 18\ \mathrm{kg})(0.55\ \mathrm{m/s^2}) = 58\ \mathrm{N}$
2. The work done by the intern, W, is the force times the distance: $W = Fd = (58\ \mathrm{N})(1.9\ \mathrm{m}) = 110\ \mathrm{J}$

Part (b)

3. Use $W = Fd$ to solve for the distance d: $d = \dfrac{W}{F} = \dfrac{140\ \mathrm{J}}{58\ \mathrm{N}} = 2.4\ \mathrm{m}$

INSIGHT
You might wonder whether the work done by the intern depends on the speed of the gurney. The answer is no. The work done on an object, $W = Fd$, doesn't depend on whether the object moves through the distance d quickly or slowly. What does depend on the speed of the gurney is the *rate* at which work is done, which we discuss in detail in Section 7-4.

PRACTICE PROBLEM — PREDICT/CALCULATE
(a) If the total mass of the gurney plus patient is halved and the acceleration is doubled, does the work done by the intern increase, decrease, or remain the same? Explain. **(b)** Determine the work in this case. [**Answer: (a)** The work remains the same because the two changes offset one another; that is, $F = ma = (m/2)(2a)$. **(b)** The work is 110 J, as before.]

Some related homework problems: Problem 3, Problem 4

NEW! 50% UPDATED AND REVISED FULLY WORKED EXAMPLES

provide a systematic process for solving problems:

- **Picture the Problem** encourages students to visualize the situation, identify and label important quantities, and set up a coordinate system. This step is accompanied by a figure and free-body diagram when appropriate.
- UPDATED! **Reasoning and Strategy** helps students learn to analyze the problem, identify the key physical concepts, and map a plan for the solution, including the Known and Unknown quantities.
- **Solution** is presented in a *two-column format* to help students translate the words of the problem on the left to the equations they will use to solve it on the right.
- **Insight** points out interesting or significant features of the problem, solution process, or the result.
- **Practice Problems** give students the opportunity to test their understanding and skills on similar problems to the one just worked.

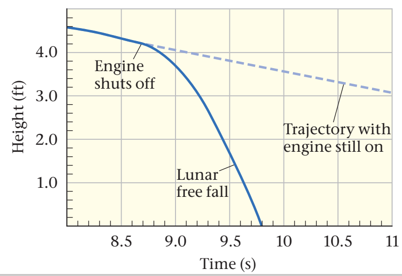
PASSAGE PROBLEMS

Bam!—*Apollo 15* Lands on the Moon

The first word spoken on the surface of the Moon after *Apollo 15* landed on July 30, 1971, was "Bam!" This was James Irwin's involuntary reaction to their rather bone-jarring touchdown. "We did hit harder than any of the other flights!" says Irwin. "And I was startled, obviously, when I said, 'Bam!'"

The reason for the "firm touchdown" of *Apollo 15,* as pilot David Scott later characterized it, was that the rocket engine was shut off a bit earlier than planned, when the lander was still 4.30 ft above the lunar surface and moving downward with a speed of 0.500 ft/s. From that point on the lander descended in lunar free fall, with an acceleration of $1.62\ \mathrm{m/s^2}$. As a result, the landing speed of *Apollo 15* was by far the largest of any of the *Apollo* missions. In comparison, Neil Armstrong's landing speed on *Apollo 11* was the lowest at 1.7 ft/s—he didn't shut off the engine until the footpads were actually on the surface. *Apollos 12, 14,* and *17* all landed with speeds between 3.0 and 3.5 ft/s.

To better understand the descent of *Apollo 15,* we show its trajectory during the final stages of landing in **FIGURE 2-47 (a)**. In **FIGURE 2-47 (b)** we show a variety of speed-versus-time plots.



NEW! END-OF-CHAPTER HOMEWORK

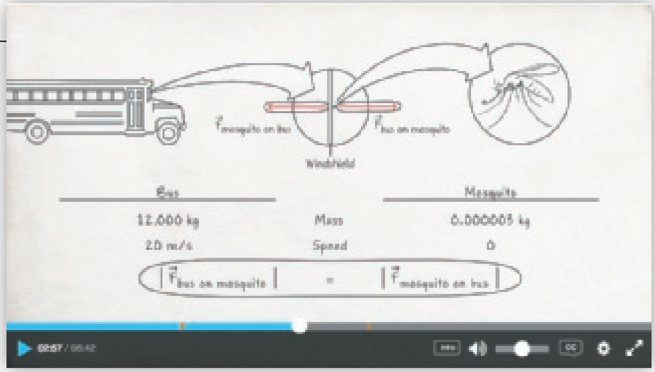
set includes 10 new problems per chapter and more than 15% revised problems. Hundreds of additional problems are available in Mastering as an alternate problem set as well as the Instructor's Solutions Manual.

NEW! BIO PASSAGE PROBLEMS

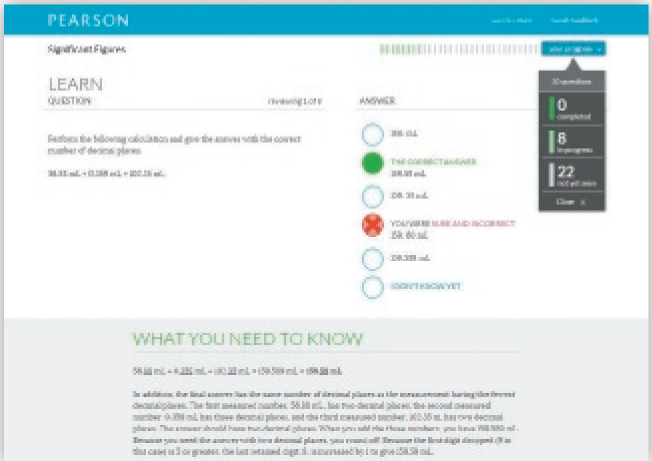
have been thoroughly rewritten to better reflect the new MCAT exam, released in 2015. With a focus on skills and core competencies, rather than rote knowledge, each Bio Passage Problem offers opportunities to practice the types of questions pre-meds will encounter on the exam.

Personalize learning with MasteringPhysics®

BEFORE CLASS

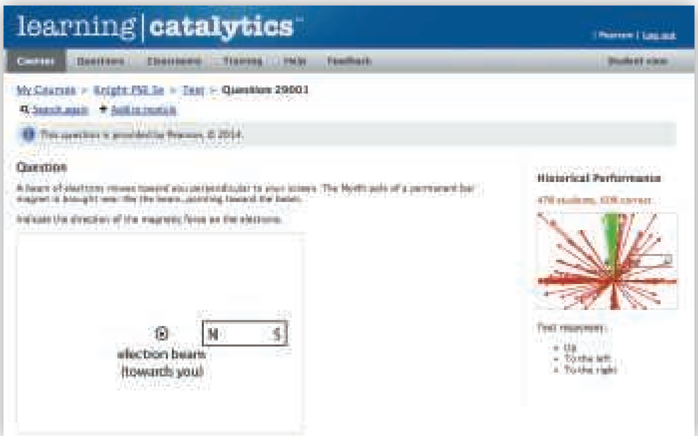


NEW! INTERACTIVE PRELECTURE VIDEOS address the rapidly growing movement toward prelecture teaching and flipped classrooms. These whiteboard-style animations provide an introduction to key topics with embedded assessment to help students prepare before lecture and to help professors identify student misconceptions.



NEW! DYNAMIC STUDY MODULES (DSMs) leverage research from the fields of cognitive psychology, neurobiology, and game studies to help students study on their own by continuously assessing their activity and performance, then using data and analytics to provide personalized content in real time to reinforce concepts that target each student's particular strengths and weaknesses. Assignable for Pre-Class Prep or Self-Study, physics DSMs include the mathematics of physics, conceptual definitions, relationships for topics across all of mechanics and electricity and magnetism, and more.

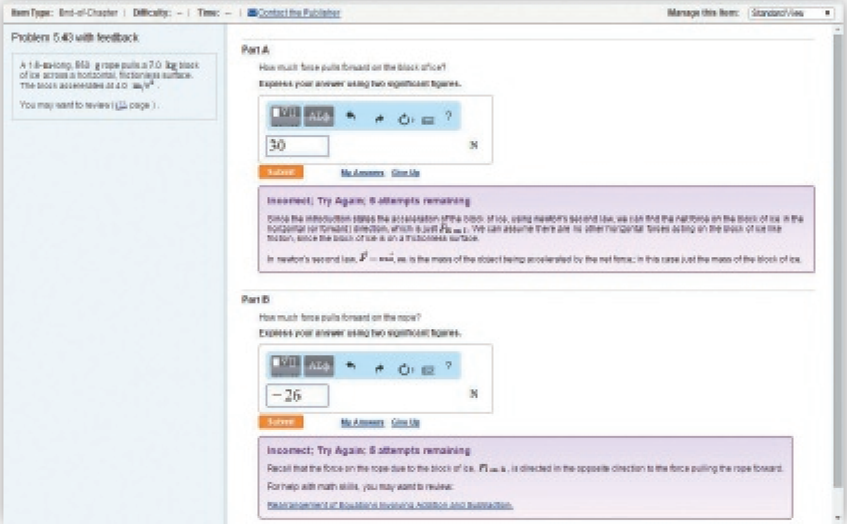
DURING CLASS

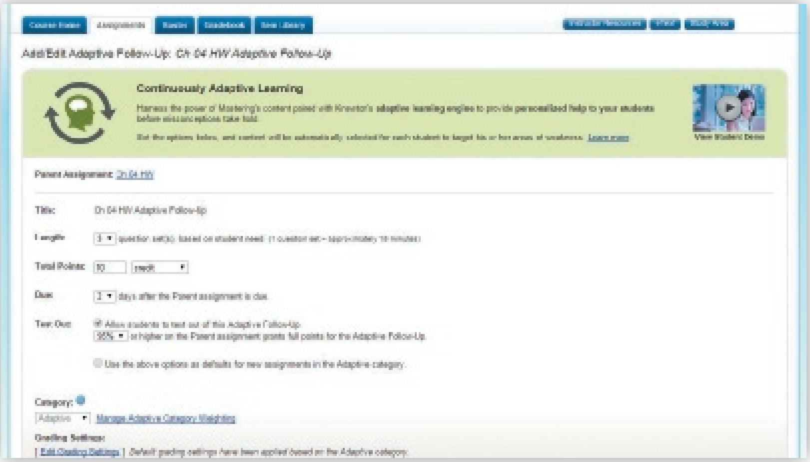


NEW! LEARNING CATALYTICS™ is an interactive classroom tool that uses students' devices to engage them in class and provide "just in time" analytics to inform your lecture/active classroom. A new math palette for the mathematical expression question type allows for Greek symbols, PI, Euler's number, Logarithm, Exponent, Trigonometric functions, Absolute value, Square root, Nth square root, and Fractions with the exception of vector or unit vector.

AFTER CLASS

NEW! ENHANCED END-OF-CHAPTER QUESTIONS offer students instructional support when and where they need it including links to the eText, math remediation, and wrong-answer specific feedback for an improved student experience and greater learning gains.





ADAPTIVE FOLLOW-UPS are personalized assignments that pair Mastering's powerful content with Knewton's adaptive learning engine to provide individualized help to students before misconceptions take hold. These adaptive follow-ups address topics students struggled with on assigned homework, including core prerequisite topics.

APPLICATIONS IN THE TEXT

Note: This list includes applied topics that receive significant discussion in the chapter text or a worked Example, as well as topics that are touched on in - end-of-chapter Conceptual Questions, Conceptual Exercises, and Problems. Topics of particular relevance to the life sciences or medicine are marked **BIO**. Topics related to Passage Problems are marked **PP**.

CHAPTER 17

CHAPTER 18

CHAPTER 19

CHAPTER 20

CHAPTER 21

CHAPTER 22

CHAPTER 23

CHAPTER 24

CHAPTER 25

CHAPTER 26

CHAPTER 27

CHAPTER 28

CHAPTER 29

CHAPTER 30

CHAPTER 31

CHAPTER 32

Teaching introductory algebra-based physics can be a most challenging—and rewarding—experience. Students enter the course with a wide range of backgrounds, interests, and skills and we, the instructors, strive not only to convey the basic concepts and fundamental laws of physics, but also to give students an appreciation for its relevance and appeal.

I wrote this book to help with that task. It incorporates a number of unique and innovative pedagogical features that evolved from years of teaching experience. The materials have been tested extensively in the classroom and in focus groups, and refined based on comments from students and teachers who used the earlier editions of the text. The enthusiastic response I've received from users of the first four editions is both flattering and motivating. The Fifth Edition has been improved in direct response to this feedback with new and revised examples; modern biological and real-world physics applications woven into the text; a refreshed homework problem set, including new biological passage problems that align with the new MCAT exam; and "just in time" learning aids throughout the text.

Learning Tools in the Text

A key goal of this text is to help students make the connection between a conceptual understanding of physics and the various skills necessary to solve quantitative problems. One of the chief means to that end is an integrated system of learning tools—including fully worked Examples with solutions in two-column format, two-column Quick Examples, Conceptual Examples, and Exercises. Each of these tools is specialized to meet the needs of students at a particular point in the development of a chapter.

These needs are not always the same. Sometimes students benefit from a detailed explanation of how to tackle a particular problem; at other times it is helpful for them to explore a key idea in a conceptual context. And sometimes, all that is required is practice using a new equation or definition.

This text emulates the teaching style of successful instructors by providing the right tool at the right time and place. This "just in time" approach helps students master the new ideas and concepts as they are encountered.

In a similar spirit, two new features appear at the end of every section in each chapter to give students immediate, timely feedback on the material just covered. These features are the **Enhance Your Understanding** and the **Section Review**. The Enhance Your Understanding feature is a conceptual question designed to solidify the concepts presented in the section. Answers to the Enhance Your Understanding questions are given at the end of each chapter. The Section Review gives a brief review of the key concepts covered in that section.

WORKED EXAMPLES WITH SOLUTIONS IN TWO-COLUMN FORMAT

Examples provide students with a complete and detailed method of solving a particular type of problem. The Examples in this text are presented in a format that focuses on the basic strategies and thought processes involved in problem solving. This focus on the intimate connection between conceptual insights and problem-solving techniques encourages students to view the ability to solve problems as a logical outgrowth of conceptual understanding. In addition, the Examples encourage students to think of solving physics problems as an opportunity to exercise their innate creativity.

Each **Example** has the same basic structure:

- **Picture the Problem** This first step discusses how the physical situation can be represented visually and what such a representation can tell us about how to analyze and solve the problem. At this step, we set up a coordinate system where appropriate, and label important quantities.

- **Reasoning and Strategy** The Reasoning and Strategy section addresses the commonly asked question, "How do I get started?" It does this by providing a clear overview of the problem and helping students to identify the relevant physical principles. It then guides the student in using known relationships to map out a step-by-step path to the solution. In the Fifth Edition I've fleshed out this step to give students more thorough guidance. **UPDATED**
- **Knowns and Unknowns** Before the process of solving the problem begins, we list the quantities that are known (given), and those that are to be found. This new feature in the Reasoning and Strategy step helps students organize their thoughts, and sets a clear goal for their calculations. **NEW**
- **Solution in a Two-Column Format** In the step-by-step Solution of the problem, each step is presented with a prose statement in the left-hand column and the corresponding mathematical implementation in the right-hand column. Each step clearly translates the idea described in words into the appropriate equations.
- **Insight** Each Example wraps up with an Insight—a comment regarding the solution just obtained. Some Insights deal with possible alternative solution techniques, others with new ideas suggested by the results.
- **Practice Problem** Following the Insight is a Practice Problem, which gives the student a chance to practice the type of calculation just presented. The Practice Problems are always accompanied by answers, and provide students with a valuable check on their understanding of the material. **Some of the Practice Problems are of the new Predict/Calculate type** in the end-of-chapter homework section. These problems ask for a prediction based on physical concepts, and then present a numerical problem to verify the prediction. Finally, each Example ends with a reference to some related end-of-chapter Problems to allow students to test their skills further. **UPDATED**

QUICK EXAMPLES

Quick Examples are streamlined versions of the full Examples. By streamlining the process, this new feature allows for more sample problems to be covered in the text without taking up too much space or becoming redundant in the details. **NEW**

CONCEPTUAL EXAMPLES

Conceptual Examples help students sharpen their insight into key physical principles. A typical Conceptual Example presents a thought-provoking question that can be answered by logical reasoning based on physical concepts rather than by numerical calculations. The statement of the question is followed by a detailed discussion and analysis in the section titled Reasoning and Discussion, and the Answer is given at the end of the checkpoint for quick and easy reference.

NEW to this edition are **Conceptual Examples that prepare students to solve Predict/Explain** problems in the end-of-chapter homework section. These problems ask for a prediction, and then ask the student to pick the best explanation from those provided.

EXERCISES

Exercises present brief one-step calculations designed to illustrate the application of important new relationships, without the expenditure of time and space required by a fully worked Example or Quick Example. Exercises generally give students an opportunity to practice the use of a new equation, become familiar with the units of a new physical quantity, and get a feeling for typical magnitudes.

PROBLEM-SOLVING NOTES

Each chapter includes a number of Problem-Solving Notes presented in a "just in time" fashion in the margin. These practical hints are designed to highlight useful problem-solving methods while helping students avoid common pitfalls and misconceptions.

End-of-Chapter Learning Tools

The end-of-chapter material in this text also includes a number of innovations, along with refinements of more familiar elements.

- Each chapter concludes with a **Chapter Summary** presented in an easy-to-use outline style. Key concepts, equations, and important figures are organized by topic for convenient reference.
- The homework for each chapter begins with a section of **Conceptual Questions**. Answers to the odd-numbered Questions can be found in the back of the book. Answers to even-numbered Conceptual Questions are available in the Instructor's Solutions Manual.
- Following the Conceptual Questions is a complete set of **Problems and Conceptual Exercises. Conceptual Exercises (CE)** consist of multiple-choice and ranking questions. Answers to the odd-numbered Exercises can be found in the back of the book. Answers to even-numbered Conceptual Exercises are available in the online Instructor's Solutions Manual.

UPDATED

- The Fifth Edition boasts a refreshed set of homework problems: at least 10 new problems per chapter and more than 15% of the previous edition problems have been revised and improved. **Problems** are divided into sections, with increasing difficulty levels indicated with one, two, or three colored bullets. Problems of particular real-world interest are indicated with titles. In addition, a section titled **General Problems** presents a variety of problems that use material from two or more sections within the chapter, or refer to material covered in earlier chapters.
- **Bio/Med Problems** are homework problems of special biological or medical relevance. These problems are indicated with the symbol **BIO**.

NEW

- **Predict/Calculate** is a new type of problem that combines a conceptual question (prediction) with a numerical problem (calculation). Problems of this type, which stress the importance of reasoning from basic principles, show how conceptual insight and numerical calculation go hand in hand in physics.
- **Predict/Explain** problems ask students to predict what will happen in a given physical situation, and then to choose the best explanation for their prediction.

UPDATED

- **Passage Problems** are based on an extended multi-paragraph description of a physical situation. These problems are similar to those found on MCAT exams, and have associated multiple-choice questions. All of the Passage Problems in the book are either new or revised and support the new MCAT released in 2015.

Perspective Across Chapters

It's easy for students to miss the forest for the trees—to overlook the unifying concepts that are central to physics and make the details easier to learn, understand, and retain. To address this difficulty, the Fifth Edition adds a **NEW** feature called **Physics In Context**. This feature, which appears in the margin at appropriate locations in the chapters, comes in two varieties—**Looking Back** and **Looking Ahead**. The Looking Back variety connects material just developed to related material from earlier chapters. This helps students apply their understanding of earlier material to a new situation, and provides a greater perspective on physics as a whole. The Looking Ahead variety gives students a "heads up" that the material presented in this chapter is important at a specific point later in the text. With these two varieties working together, Physics In Context helps students develop connections between different topics in physics that share a common central theme.

PHYSICS IN CONTEXT
Looking Back

Conservation of energy, first introduced in Chapter 8, is just as important in rotational motion as it is in linear motion.

PHYSICS IN CONTEXT
Looking Ahead

In Chapter 5 we will introduce one of the most important concepts in all of physics—force. It is a vector quantity. Other important vector quantities to be introduced in later chapters include linear momentum (Chapter 9), angular momentum (Chapter 11), electric field (Chapter 19), and magnetic field (Chapter 22).

Scope and Organization

The presentation of physics in this text follows the standard practice for introductory courses, with only a few well-motivated refinements.

First, note that Chapter 3 is devoted to **vectors and their application to physics**. My experience has been that students benefit greatly from a full discussion of vectors early in the course. Most students have seen vectors and trigonometric functions before, but rarely from the point of view of physics. Thus, including a chapter on vectors sends a message that this is important material, and gives students an opportunity to develop and improve their understanding of vectors in a physics context.

Note also that **additional time is given to some of the more fundamental aspects of physics**, such as Newton's laws and energy. Presenting such material in two chapters gives the student a better opportunity to assimilate and master these crucial topics.

REAL-WORLD AND BIOLOGICAL PHYSICS

UPDATED

Since physics applies to everything in nature, it's only reasonable to point out applications of physics that students may encounter in the real world. Each chapter presents a number of discussions focusing on "Real-World Physics." Those of general interest are designated by **RWP** at the start of the paragraph. Applications that pertain more specifically to biology or medicine are indicated by **BIO**.

These applications have been thoughtfully updated with topics that are current and relevant to today's student. For example, new **RWP** features include timely discussions of accelerometers in cell phones and game controllers (Chapter 2), traffic collision avoidance systems (Chapter 4), the tension in a tether connecting astronauts in the movie *Gravity* (Chapter 6), and the use of magnetic forces to improve recycling (Chapter 22). Updated **BIO** topics include the deadly blow delivered by a mantis shrimp (Chapter 8), the 1000-rpm mid-air spinning behavior of dragonflies (Chapter 10), how starfish use torque to open clamshells (Chapter 11), and how radioactivity is used to treat hyperactive thyroids (Chapter 32).

These new applications are in addition to the many classic, and often surprising, examples of physics that have always been an important part of Walker *Physics*. Examples like these engage a student's interest, and help motivate them to think more deeply about physics concepts. Students are often intrigued, for example, to discover that they are shorter at the end of the day than when they get up in the morning (Chapter 5), that humming next to a spider web can cause a resonance effect that sends the spider into a tizzy (Chapter 13), and that scorpions in the nighttime desert are brightly fluorescent when illuminated by an ultraviolet flashlight (Chapter 31). With real-world applications like these, it's easy to show students that physics is relevant to their everyday lives.

VISUALS

One of the most fundamental ways in which we learn is by comparing and contrasting. A new feature called **Visualizing Concepts** helps with this process by presenting a selection of photos that illustrate a physical concept in a variety of different contexts. Grouping carefully chosen photographs in this way helps students to see the universality of physics. We have also included a number of **demonstration photos** that use high-speed time-lapse photography to dramatically illustrate topics, such as standing waves, static versus kinetic friction, and the motion of center of mass, in a way that reveals physical principles in the world around us.

Resources

The Fifth Edition is supplemented by an ancillary package developed to address the needs of both students and instructors.

FOR THE INSTRUCTOR

Instructor's Solutions Manual by Kenneth L. Menningen (University of Wisconsin–Stevens Point) is available online at the Instructor's Resource Center: www.pearsonhighered.com/educator, on the Instructor's Resource DVD, and in the Instructor's Resource Area on Mastering. You will find detailed, worked solutions to every Problem and Conceptual Exercise in the text, all solved using the step-by-step problem-solving strategy of the in-chapter Examples (Picture the Problem, Reasoning and Strategy, two-column Solutions, and Insight). The solutions also contain answers to the even-numbered Conceptual Questions as well as problem statements and solutions for the hundreds of problems in the alternate problem set in Mastering.

The cross-platform **Instructor's Resource DVD** (ISBN 978-0-321-76570-3) provides a comprehensive library of applets from ActivPhysics OnLine as well as PhET simulations. All line figures, photos, and examples from the textbook are provided in JPEG format and the key equations are available in editable Word files. A revised set of Lecture Outlines and Clicker questions, both in PowerPoint, are included for use in lecture. Assets available in Mastering are provided here, too: Pause and Predict Video Tutor Demonstrations and Author Demonstration Videos. And it includes the Test Bank in Word and TestGen formats and the Instructor's Solutions Manual in Word and pdf.

MP **MasteringPhysics®** (www.masteringphysics.com) is the most advanced, educationally effective, and widely used physics homework and tutorial system in the world. Ten years in development, it provides instructors with a library of extensively pre-tested end-of-chapter problems and rich multipart, multistep tutorials that incorporate a wide variety of answer types, wrong answer feedback, individualized help (comprising hints or simpler sub-problems upon request), all driven by the largest metadatabase of student problem-solving in the world.

New to MasteringPhysics:

NEW **Interactive Prelecture Videos** address the rapidly growing movement toward prelecture teaching and flipped classrooms. These whiteboard-style animations provide an introduction to key topics with embedded assessment to help students prepare before lecture and to help professors identify student misconceptions.

NEW **Dynamic Study Modules (DSMs)** leverage research from the fields of cognitive psychology, neurobiology, and game studies to help students study on their own by continuously assessing their activity and performance, then using data and analytics to provide personalized content in real-time to reinforce concepts that target each student's particular strengths and weaknesses. Assignable for Pre-Class Prep or Self-Study, physics DSMs include the mathematics of physics, conceptual definitions, relationships for topics across all of mechanics and electricity and magnetism, and more.

Learning Catalytics™ is an interactive classroom tool that uses students' devices to engage them in class and provide "just in time" analytics to inform your lecture/active classroom. A new math palette for the mathematical expression question type allows for Greek symbols, PI, Euler's number, Logarithm, Exponent, Trigonometric functions, Absolute value, Square root, Nth square root, and Fractions with the exception of vector or unit vector. NEW

Enhanced End-of-Chapter Questions offer students instructional support when and where they need it including links to the eText, math remediation, and wrong-answer specific feedback for an improved student experience and greater learning gains. NEW

Adaptive Follow-Ups are personalized assignments that pair Mastering's powerful content with Knewton's adaptive learning engine to provide individualized help to students before misconceptions take hold. These adaptive follow-ups address topics students struggled with on assigned homework, including core prerequisite topics.

An **alternate set of hundreds of homework problems** not included in the textbook gives instructors more assignable homework options than before. Solutions and problem statements are available in the Instructor's Solutions Manual. NEW

MCAT questions are a set of multipart passage problems and standalone problems in a biological context that cover the key topics of the new 2015 MCAT format. NEW

Video Tutor Demomonstration coaching activities give brief demonstrations that include "Pause and Predict" questions with Mastering assessment containing wrong answer feedback and hints. NEW

The **Test Bank** contains more than 2000 high-quality problems assignable as auto-graded items in MasteringPhysics. Test files are provided both in TestGen (an easy-to-use, fully networkable program for creating and editing quizzes and exams) and Word formats. Available in the

MasteringPhysics Instructor's Area, on the Instructor's Resource Center (www.pearsonhighered.com/irc), and on the Instructor's Resource DVD.

FOR THE STUDENT

MasteringPhysics® (www.masteringphysics.com) is the most advanced physics homework and tutorial system available. This online homework and tutoring system guides students through the most important topics in physics with self-paced tutorials that provide individualized coaching. These assignable, in-depth tutorials are designed to coach students with hints and feedback specific to their individual errors. Instructors can also assign end-of-chapter problems from every chapter including multiple-choice questions, section-specific exercises, and general problems. Quantitative problems can be assigned with numerical answers and randomized values (with sig fig feedback) or solutions. Mastering is available either bundled with the textbook, as an online download—with or without the eText—and as a standalone item available for purchase at the campus bookstore.

Pearson eText is available through MasteringPhysics®, either automatically when MasteringPhysics® is packaged with new books or as a purchased upgrade online. Allowing students access to the text wherever they have access to the Internet, Pearson eText comprises the full text with additional interactive features. Users can search for words or phrases, create notes, highlight text, bookmark sections, and click on definitions to key terms as they read.

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PREFACE: TO THE STUDENT

As a student preparing to take an algebra-based physics course, you are probably aware that physics applies to absolutely everything in the natural world, from raindrops and people, to galaxies and atoms. Because physics is so wide-ranging and comprehensive, it can sometimes seem a bit overwhelming. This text, which reflects nearly two decades of classroom experience, is designed to help you deal with a large body of information and develop a working understanding of the basic concepts in physics. Now in its fifth edition, it incorporates many refinements that have come directly from interacting with students using the first four editions. As a result of these interactions, I am confident that as you develop a deeper understanding of physics, you will also enrich your experience of the world in which you live.

Now, I must admit that I like physics, and so I may be a bit biased in this respect. Still, the reason I teach and continue to study physics is that I enjoy the insight it gives into the physical world. I can't help but notice—and enjoy—aspects of physics all around me each and every day. I would like to share some of this enjoyment and delight in the natural world with you. It is for this reason that I undertook the task of writing this book.

To assist you in the process of studying physics, this text incorporates a number of learning aids, including two-column Examples, Quick Examples, Conceptual Examples, and Exercises. These and other elements work together in a unified way to enhance your understanding of physics on both a conceptual and a quantitative level—they have been developed to give you the benefit of what we know about how students learn physics, and to incorporate strategies that have proven successful to students over the years. The pages that follow will introduce these elements to you, describe the purpose of each, and explain how they can help you.

As you progress through the text, you will encounter many interesting and intriguing applications of physics drawn from the world around you. Some of these, such as magnetically levitated trains or the Global Positioning System (GPS), are primarily technological in nature. Others focus on explaining familiar or not-so-familiar phenomena, such as why the Moon has no atmosphere, how sweating cools the body, or why flying saucer shaped clouds often hover over mountain peaks even on a clear day. Still others, such as countercurrent heat exchange in animals and humans, or the use of sound waves to destroy kidney stones, are of particular relevance to students of biology and those interested in pursuing a career in medicine.

In many cases, you may find the applications to be a bit surprising. Did you know, for example, that you are shorter at the end of the day than when you first get up in the morning? (This is discussed in Chapter 5.) That an instrument called the ballistocardiograph can detect the presence of a person hiding in a truck, just by registering the minute recoil from the beating of the stowaway's heart? (This is discussed in Chapter 9.) That if you hum next to a spider's web at just the right pitch you can cause a resonance effect that sends the spider into a tizzy? (This is discussed in Chapter 13.) That powerful magnets can exploit the phenomenon of diamagnetism to levitate living creatures? (This is discussed in Chapter 22.) That scorpions in the nighttime desert are brightly fluorescent when illuminated by ultraviolet light? (This is discussed in Chapter 31.) The natural world truly is filled with marvelous things, and physics applies to all of them.

Writing this textbook was a rewarding and enjoyable experience for me. I hope using it will prove equally rewarding to you, and that it will inspire an appreciation for physics that will give you a lifetime of enjoyment.

James S. Walker

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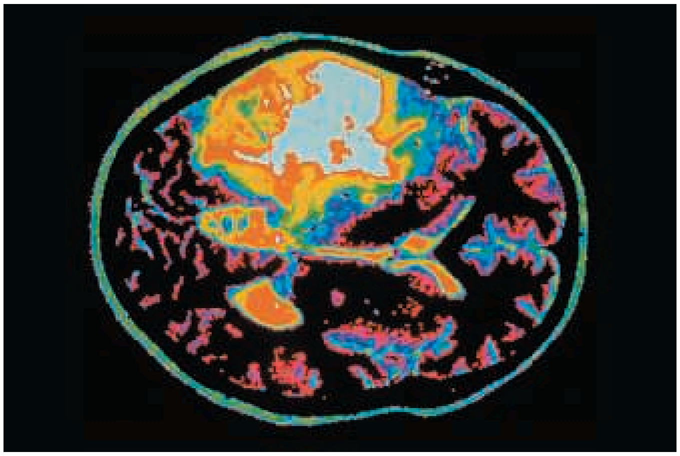

PHYSICS

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MATHEMATICAL SYMBOLS

$=$	is equal to
$\neq$	is not equal to
$\approx$	is approximately equal to
$\propto$	is proportional to
$>$	is greater than
$\geq$	is greater than or equal to
$\gg$	is much greater than
$<$	is less than
$\leq$	is less than or equal to
$\ll$	is much less than
$\pm$	plus or minus
$\mp$	minus or plus
x_{av} or $\bar{x}$	average value of x
Δx	change in x $(x_f - x_i)$
$\lvert x \rvert$	absolute value of x
Σ	sum of
$\rightarrow 0$	approaches 0
∞	infinity

USEFUL MATHEMATICAL FORMULAS

Area of a triangle	$\frac{1}{2}bh$
Area of a circle	πr^2
Circumference of a circle	$2\pi r$
Surface area of a sphere	$4\pi r^2$
Volume of a sphere	$\frac{4}{3}\pi r^3$
Pythagorean theorem	$r^2 = x^2 + y^2$
Quadratic formula	if $ax^2 + bx + c = 0$, then $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

EXPONENTS AND LOGARITHMS

$x^n x^m = x^{n+m}$

$x^{-n} = \dfrac{1}{x^n}$ $\qquad \ln(xy) = \ln x + \ln y$

$\dfrac{x^n}{x^m} = x^{n-m}$ $\qquad \ln\left(\dfrac{x}{y}\right) = \ln x - \ln y$

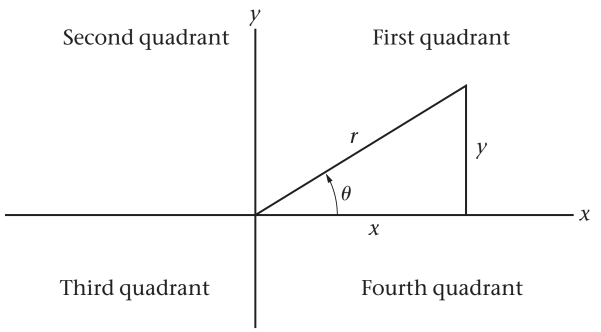
$(xy)^n = x^n y^n$ $\qquad \ln x^n = n \ln x$

$(x^n)^m = x^{nm}$

VALUES OF SOME USEFUL NUMBERS

$\pi = 3.14159\ldots$	$\log 2 = 0.30103\ldots$	$\sqrt{2} = 1.41421\ldots$
$e = 2.71828\ldots$	$\ln 2 = 0.69315\ldots$	$\sqrt{3} = 1.73205\ldots$

TRIGONOMETRIC RELATIONSHIPS



Definitions of Trigonometric Functions

$\sin\theta = \dfrac{y}{r}$ $\qquad \cos\theta = \dfrac{x}{r}$ $\qquad \tan\theta = \dfrac{\sin\theta}{\cos\theta} = \dfrac{y}{x}$

Trigonometric Functions of Important Angles

$\theta°$(rad)	$\sin\theta$	$\cos\theta$	$\tan\theta$
$0°(0)$	0	1	0
$30°(\pi/6)$	0.500	$\sqrt{3}/2 \approx 0.866$	$\sqrt{3}/3 \approx 0.577$
$45°(\pi/4)$	$\sqrt{2}/2 \approx 0.707$	$\sqrt{2}/2 \approx 0.707$	1.00
$60°(\pi/3)$	$\sqrt{3}/2 \approx 0.866$	0.500	$\sqrt{3} \approx 1.73$
$90°(\pi/2)$	1	0	∞

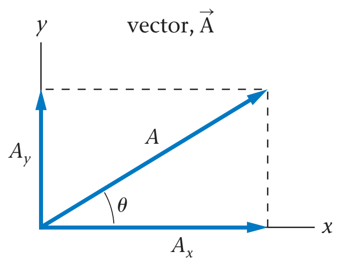
Trigonometric Identities

$\sin(\theta + \phi) = \sin\theta\cos\phi + \sin\phi\cos\theta$

$\cos(\theta + \phi) = \cos\theta\cos\phi - \sin\theta\sin\phi$

$\sin 2\theta = 2\sin\theta\cos\theta$

VECTOR MANIPULATIONS



Magnitude and direction	$\longleftrightarrow$	x and y components
A, θ	$\longrightarrow$	$A_x = A\cos\theta$ $A_y = A\sin\theta$
$A = \sqrt{A_x{}^2 + A_y{}^2}$ $\theta = \tan^{-1}\left(\dfrac{A_y}{A_x}\right)$	$\longleftarrow$	A_x, A_y

CONVERSION FACTORS

Mass

$1\ \text{kg} = 10^3\ \text{g}$
$1\ \text{g} = 10^{-3}\ \text{kg}$
$1\ \text{u} = 1.66 \times 10^{-24}\ \text{g} = 1.66 \times 10^{-27}\ \text{kg}$
$1\ \text{slug} = 14.6\ \text{kg}$
$1\ \text{metric ton} = 1000\ \text{kg}$

Length

$1\ \text{Å} = 10^{-10}\ \text{m}$
$1\ \text{nm} = 10^{-9}\ \text{m}$
$1\ \text{cm} = 10^{-2}\ \text{m} = 0.394\ \text{in.}$
$1\ \text{yd} = 3\ \text{ft}$
$1\ \text{m} = 10^{-3}\ \text{km} = 3.281\ \text{ft} = 39.4\ \text{in.}$
$1\ \text{km} = 10^3\ \text{m} = 0.621\ \text{mi}$
$1\ \text{in.} = 2.54\ \text{cm} = 2.54 \times 10^{-2}\ \text{m}$
$1\ \text{ft} = 0.305\ \text{m} = 30.5\ \text{cm}$
$1\ \text{mi} = 5280\ \text{ft} = 1609\ \text{m} = 1.609\ \text{km}$
$1\ \text{ly (light year)} = 9.46 \times 10^{12}\ \text{km}$
$1\ \text{pc (parsec)} = 3.09 \times 10^{13}\ \text{km}$

Area

$1\ \text{cm}^2 = 10^{-4}\ \text{m}^2 = 0.1550\ \text{in.}^2 = 1.08 \times 10^{-3}\ \text{ft}^2$
$1\ \text{m}^2 = 10^4\ \text{cm}^2 = 10.76\ \text{ft}^2 = 1550\ \text{in.}^2$
$1\ \text{in.}^2 = 6.94 \times 10^{-3}\ \text{ft}^2 = 6.45\ \text{cm}^2 = 6.45 \times 10^{-4}\ \text{m}^2$
$1\ \text{ft}^2 = 144\ \text{in.}^2 = 9.29 \times 10^{-2}\ \text{m}^2 = 929\ \text{cm}^2$

Volume

$1\ \text{cm}^3 = 10^{-6}\ \text{m}^3 = 3.35 \times 10^{-5}\ \text{ft}^3 = 6.10 \times 10^{-2}\ \text{in.}^3$
$1\ \text{m}^3 = 10^6\ \text{cm}^3 = 10^3\ \text{L} = 35.3\ \text{ft}^3 = 6.10 \times 10^4\ \text{in.}^3 = 264\ \text{gal}$
$1\ \text{liter} = 10^3\ \text{cm}^3 = 10^{-3}\ \text{m}^3 = 1.056\ \text{qt} = 0.264\ \text{gal}$
$1\ \text{in.}^3 = 5.79 \times 10^{-4}\ \text{ft}^3 = 16.4\ \text{cm}^3 = 1.64 \times 10^{-5}\ \text{m}^3$
$1\ \text{ft}^3 = 1728\ \text{in.}^3 = 7.48\ \text{gal} = 0.0283\ \text{m}^3 = 28.3\ \text{L}$
$1\ \text{qt} = 2\ \text{pt} = 946\ \text{cm}^3 = 0.946\ \text{L}$
$1\ \text{gal} = 4\ \text{qt} = 231\ \text{in.}^3 = 0.134\ \text{ft}^3 = 3.785\ \text{L}$

Time

$1\ \text{h} = 60\ \text{min} = 3600\ \text{s}$
$1\ \text{day} = 24\ \text{h} = 1440\ \text{min} = 8.64 \times 10^4\ \text{s}$
$1\ \text{y} = 365\ \text{days} = 8.76 \times 10^3\ \text{h} = 5.26 \times 10^5\ \text{min} = 3.16 \times 10^7\ \text{s}$

Speed

$1\ \text{m/s} = 3.60\ \text{km/h} = 3.28\ \text{ft/s} = 2.24\ \text{mi/h}$
$1\ \text{km/h} = 0.278\ \text{m/s} = 0.621\ \text{mi/h} = 0.911\ \text{ft/s}$
$1\ \text{ft/s} = 0.682\ \text{mi/h} = 0.305\ \text{m/s} = 1.10\ \text{km/h}$
$1\ \text{mi}/h = 1.467\ \text{ft/s} = 1.609\ \text{km/h} = 0.447\ \text{m/s}$
$60\ \text{mi/h} = 88\ \text{ft/s}$

Force

$1\ \text{N} = 0.225\ \text{lb}$
$1\ \text{lb} = 4.45\ \text{N}$
Equivalent weight of a mass of 1 kg on Earth's surface $= 2.2\ \text{lb} = 9.8\ \text{N}$
$1\ \text{dyne} = 10^{-5}\ \text{N} = 2.25 \times 10^{-6}\ \text{lb}$

Pressure

$1\ \text{Pa} = 1\ \text{N/m}^2 = 1.45 \times 10^{-4}\ \text{lb/in.}^2 = 7.5 \times 10^{-3}\ \text{mm Hg}$
$1\ \text{mm Hg} = 133\ \text{Pa} = 0.02\ \text{lb/in.}^2 = 1\ \text{torr}$
$1\ \text{atm} = 14.7\ \text{lb/in.}^2 = 101.3\ \text{kPa} = 30\ \text{in. Hg} = 760\ \text{mm Hg}$
$1\ \text{lb/in.}^2 = 6.89\ \text{kPa}$
$1\ \text{bar} = 10^5\ \text{Pa} = 100\ \text{kPa}$
$1\ \text{millibar} = 10^2\ \text{Pa}$

Energy

$1\ \text{J} = 0.738\ \text{ft}\cdot\text{lb} = 0.239\ \text{cal} = 9.48 \times 10^{-4}\ \text{Btu} = 6.24 \times 10^{18}\ \text{eV}$
$1\ \text{kcal} = 4186\ \text{J} = 3.968\ \text{Btu}$
$1\text{Btu} = 1055\ \text{J} = 778\ \text{ft}\cdot\text{lb} = 0.252\ \text{kcal}$
$1\ \text{cal} = 4.186\ \text{J} = 3.97 \times 10^{-3}\ \text{Btu} = 3.09\ \text{ft}\cdot\text{lb}$
$1\ \text{ft}\cdot\text{lb} = 1.36\ \text{J} = 1.29 \times 10^{-3}\ \text{Btu}$
$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$
$1\ \text{kWh} = 3.6 \times 10^6\ \text{J}$
$1\ \text{erg} = 10^{-7}\ \text{J} = 7.38 \times 10^{-6}\ \text{ft}\cdot\text{lb}$

Power

$1\ \text{W} = 1\ \text{J/s} = 0.738\ \text{ft}\cdot\text{lb/s} = 1.34 \times 10^{-3}\ \text{hp} = 3.41\ \text{Btu/h}$
$1\ \text{ft}\cdot\text{lb/s} = 1.36\ \text{W} = 1.82 \times 10^{-3}\ \text{hp}$
$1\ \text{hp} = 550\ \text{ft}\cdot\text{lb/s} = 745.7\ \text{W} = 2545\ \text{Btu/h}$

Mass–Energy Equivalents

$1\ \text{u} = 1.66 \times 10^{-27}\ \text{kg} \leftrightarrow 931.5\ \text{MeV}$
$1\ \text{electron mass} = 9.11 \times 10^{-31}\ \text{kg} = 5.49 \times 10^{-4}\ \text{u} \leftrightarrow 0.511\ \text{MeV}$
$1\ \text{proton mass} = 1.673 \times 10^{-27}\ \text{kg} = 1.007\,267\ \text{u} \leftrightarrow 938.28\ \text{MeV}$
$1\ \text{neutron mass} = 1.675 \times 10^{-27}\ \text{kg} = 1.008\,665\ \text{u} \leftrightarrow 939.57\ \text{MeV}$

Temperature

$T_F = \frac{9}{5} T_C + 32$
$T_C = \frac{5}{9}(T_F - 32)$
$T_K = T_C + 273.15$

Angle

$1\ \text{rad} = 57.3°$

$1° = 0.0175\ \text{rad}$	$60° = \pi/3\ \text{rad}$
$15° = \pi/12\ \text{rad}$	$90° = \pi/2\ \text{rad}$
$30° = \pi/6\ \text{rad}$	$180° = \pi\ \text{rad}$
$45° = \pi/4\ \text{rad}$	$360° = 2\pi\ \text{rad}$

$1\ \text{rev/min} = (\pi/30)\ \text{rad/s} = 0.1047\ \text{rad/s}$

APPENDICES IN THE TEXT

MULTIPLES AND PREFIXES FOR METRIC UNITS

Multiple	Prefix (Abbreviation)	Pronunciation
10^{24}	yotta- (Y)	yot′ta (*a* as in *a*bout)
10^{21}	zetta- (Z)	zet′ta (*a* as in *a*bout)
10^{18}	exa- (E)	ex′a (*a* as in *a*bout)
10^{15}	peta- (P)	pet′a (as in *petal*)
10^{12}	tera- (T)	ter′a (as in *terrace*)
10^{9}	giga- (G)	ji′ga (*ji* as in *ji*ggle, *a* as in *a*bout)
10^{6}	mega- (M)	meg′a (as in *mega*phone)
10^{3}	kilo- (k)	kil′o (as in *kilo*watt)
10^{2}	hecto- (h)	hek′to (*heck-toe*)
10	deka- (da)	dek′a (*deck* plus *a* as in *a*bout)
10^{-1}	deci- (d)	des′i (as in *deci*mal)
10^{-2}	centi- (c)	sen′ti (as in *senti*mental)
10^{-3}	milli- (m)	mil′li (as in *mili*tary)
10^{-6}	micro- (μ)	mi′kro (as in *micro*phone)
10^{-9}	nano- (n)	nan′oh (*an* as in *an*nual)
10^{-12}	pico- (p)	pe′ko (*peek-oh*)
10^{-15}	femto- (f)	fem′toe (*fem* as in *fem*inine)
10^{-18}	atto- (a)	at′toe (as in an*atomy*)
10^{-21}	zepto- (z)	zep′toe (as in *zep*pelin)
10^{-24}	yocto- (y)	yock′toe (as in *sock*)

THE GREEK ALPHABET

Alpha	A	α
Beta	B	β
Gamma	Γ	γ
Delta	Δ	δ
Epsilon	E	ε
Zeta	Z	ζ
Eta	H	η
Theta	Θ	θ
Iota	I	ι
Kappa	K	κ
Lambda	Λ	λ
Mu	M	μ
Nu	N	ν
Xi	Ξ	ξ
Omicron	O	o
Pi	Π	π
Rho	P	ρ
Sigma	Σ	σ
Tau	T	τ
Upsilon	Y	υ
Phi	Φ	ϕ
Chi	X	χ
Psi	Ψ	ψ
Omega	Ω	ω

SI BASE UNITS

Physical Quantity	Name of Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

SOME SI DERIVED UNITS

Physical Quantity	Name of Unit	Symbol	SI Unit
Frequency	hertz	Hz	s^{-1}
Energy	joule	J	$kg \cdot m^2/s^2$
Force	newton	N	$kg \cdot m/s^2$
Pressure	pascal	Pa	$kg/(m \cdot s^2)$
Power	watt	W	$kg \cdot m^2/s^3$
Electric charge	coulomb	C	$A \cdot s$
Electric potential	volt	V	$kg \cdot m^2/(A \cdot s^3)$
Electric resistance	ohm	Ω	$kg \cdot m^2/(A^2 \cdot s^3)$
Capacitance	farad	F	$A^2 \cdot s^4/(kg \cdot m^2)$
Inductance	henry	H	$kg \cdot m^2/(A^2 \cdot s^2)$
Magnetic field	tesla	T	$kg/(A \cdot s^2)$
Magnetic flux	weber	Wb	$kg \cdot m^2/(A \cdot s^2)$

SI UNITS OF SOME OTHER PHYSICAL QUANTITIES

Physical Quantity	SI Unit
Density (ρ)	kg/m^3
Speed (v)	m/s
Acceleration (a)	m/s^2
Momentum, impulse (p)	$kg \cdot m/s$
Angular speed (ω)	rad/s
Angular acceleration (α)	rad/s^2
Torque (τ)	$kg \cdot m^2/s^2$ *or* $N \cdot m$
Specific heat (c)	$J/(kg \cdot K)$
Thermal conductivity (k)	$W/(m \cdot K)$ *or* $J/(s \cdot m \cdot K)$
Entropy (S)	J/K *or* $kg \cdot m^2/(K \cdot s^2)$ *or* $N \cdot m/K$
Electric field (E)	N/C or V/m

APPENDICES IN THE TEXT

FUNDAMENTAL CONSTANTS

Quantity	Symbol	Approximate Value
Speed of light	c	3.00×10^8 m/s $= 3.00 \times 10^{10}$ cm/s $= 186{,}000$ mi/s
Universal gravitational constant	G	$6.67 \times 10^{-11}\ \mathrm{N \cdot m^2/kg^2}$
Stefan-Boltzmann constant	σ	$5.67 \times 10^{-8}\ \mathrm{W/(m^2 \cdot K^4)}$
Boltzmann's constant	k	1.38×10^{-23} J/K
Avogadro's number	N_A	$6.022 \times 10^{23}\ \mathrm{mol^{-1}}$
Gas constant	$R = N_A k$	$8.31\ \mathrm{J/(mol \cdot K)} = 1.99\ \mathrm{cal/(mol \cdot K)}$
Coulomb's law constant	$k = 1/4\pi\epsilon_0$	$8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2}$
Electron charge	e	1.60×10^{-19} C
Permittivity of free space	ϵ_o	$8.85 \times 10^{-12}\ \mathrm{C^2/(N \cdot m^2)}$
Permeability of free space	μ_o	$4\pi \times 10^{-7}\ \mathrm{T \cdot m/A} = 1.26 \times 10^{-6}\ \mathrm{T \cdot m/A}$
Planck's constant	h	$6.63 \times 10^{-34}\ \mathrm{J \cdot s}$
	$\hbar = h/2\pi$	$1.05 \times 10^{-34}\ \mathrm{J \cdot s}$
Atomic mass unit	u	1.6605×10^{-27} kg $\leftrightarrow$ 931.5 MeV
Electron mass	m_e	9.10939×10^{-31} kg $= 5.49 \times 10^{-4}$ u $\leftrightarrow$ 0.511 MeV
Neutron mass	m_n	$1.675\,00 \times 10^{-27}$ kg $= 1.008\ 665$ u $\leftrightarrow$ 939.57 MeV
Proton mass	m_p	$1.672\,65 \times 10^{-27}$ kg $= 1.007\,267$ u $\leftrightarrow$ 938.28 MeV

USEFUL PHYSICAL DATA

Acceleration due to gravity (surface of Earth)	$9.81\ \mathrm{m/s^2} = 32.2\ \mathrm{ft/s^2}$
Absolute zero	0 K = −273.15°C = −459.67°F
Standard temperature & pressure (STP)	0°C = 273.15 K
	1 atm = 101.325 kPa
Density of air (STP)	$1.29\ \mathrm{kg/m^3}$
Speed of sound in air (20 °C)	343 m/s
Density of water (4 °C)	$1.000 \times 10^3\ \mathrm{kg/m^3}$
Latent heat of fusion of water	3.35×10^5 J/kg
Latent heat of vaporization of water	2.26×10^6 J/kg
Specific heat of water	$4186\ \mathrm{J/(kg \cdot K)}$

SOLAR SYSTEM DATA*

Equatorial radius of Earth	6.37×10^3 km = 3950 mi
Mass of Earth	5.97×10^{24} kg
Radius of Moon	1740 km = 1080 mi
Mass of Moon	7.35×10^{22} kg $\approx \frac{1}{81}$ mass of Earth
Average distance of Moon from Earth	3.84×10^5 km $= 2.39 \times 10^5$ mi
Radius of Sun	6.95×10^5 km = 432,000 mi
Mass of Sun	2.00×10^{30} kg
Average distance of Earth from Sun	1.50×10^8 km $= 93.0 \times 10^6$ mi

*See Appendix C for additional planetary data.

1

Introduction to Physics

Big Ideas

1. Physics is the study of the laws of nature.
2. The basic units in physics are length, mass, and time.
3. Valid physics equations must be dimensionally consistent.
4. Some physical quantities are scalars; others are vectors.

▲ Physics is a quantitative science, based on careful measurements of quantities such as mass, length, and time. In the measurement shown here, a naturalist determines the mass of a cooperative penguin. The length of the penguin, and its age, are also important data in monitoring the penguin's health.

The goal of physics is to gain a deeper understanding of the world in which we live. For example, the laws of physics allow us to predict the behavior of everything from rockets sent to the Moon, to integrated chips in computers, to lasers used to perform eye surgery. In short, everything in nature—from atoms and subatomic particles to solar systems and galaxies—obeys the laws of physics. In this chapter, we develop a common "language" of physics that will be used throughout this book.

Big Idea 1 Physics is the study of the laws of nature. These laws determine the behavior of all physical objects and processes in the universe.

1-1 Physics and the Laws of Nature

Physics is the study of the fundamental laws of nature, which, simply put, are the laws that underlie all physical phenomena in the universe. Remarkably, we have found that these laws can be expressed in terms of mathematical equations. As a result, it is possible to make precise, quantitative comparisons between the predictions of theory—derived from the mathematical form of the laws—and the observations of experiments. Physics, then, is a science rooted equally firmly in both theory and experiment. As physicists make new observations, they constantly test and—if necessary—refine the present theories.

What makes physics particularly fascinating is the fact that it relates to everything in the universe. There is a great beauty in the vision that physics brings to our view of the universe—namely, that all the complexity and variety that we see in the world around us, and in the universe as a whole, are manifestations of a few fundamental laws and principles. That we can discover and apply these basic laws of nature is both astounding and exhilarating.

For those not familiar with the subject, physics may seem to be little more than a confusing mass of formulas. Sometimes, in fact, these formulas can be the trees that block the view of the forest. For a physicist, however, the many formulas of physics are simply different ways of expressing a few fundamental ideas. It is the forest—the basic laws and principles of physical phenomena in nature—that is the focus of this text.

Enhance Your Understanding

(Answers given at the end of the chapter)

1. The laws of physics apply to which of the following: **(a)** gravity, **(b)** electricity, **(c)** magnetism, **(d)** light, **(e)** atoms, or **(f)** all of these?

Section Review

- Physics combines both theory and experiment in the study of the laws of nature.

Big Idea 2 The basic units of physical quantities in the first part of this book are length, mass, and time. Later in the book, other units, like temperature and electric current, are introduced.

1-2 Units of Length, Mass, and Time

To make quantitative comparisons between the laws of physics and our experience of the natural world, certain basic physical quantities must be measured. The most common of these quantities are **length** (L), **mass** (M), and **time** (T). In fact, in the next several chapters these are the only quantities that arise. Later in the text, additional quantities, such as temperature and electric current, will be introduced as needed.

We begin by defining the units in which each of these quantities is measured. Once the units are defined, the values obtained in specific measurements can be expressed as multiples of them. For example, our unit of length is the **meter** (m). It follows, then, that a person who is 1.5 m tall has a height 1.5 times this unit of length. Similar comments apply to the unit of mass, the **kilogram**, and the unit of time, the **second**.

The detailed system of units used in this book was established in 1960 at the Eleventh General Conference on Weights and Measures in Paris, France, and goes by the name Système International d'Unités, or SI for short. Thus, when we refer to **SI units**, we mean units of meters (m), kilograms (kg), and seconds (s). Taking the first letter from each of these units leads to an alternate name that is often used—the **mks system**.

In the remainder of this section we define each of the SI units.

Length

Early units of length were often associated with the human body. For example, the Egyptians defined the cubit to be the distance from the elbow to the tip of the middle finger. Similarly, the foot was at one time defined to be the length of the royal

TABLE 1-1 Typical Distances

Distance from Earth to the nearest large galaxy (the Andromeda galaxy, M31)	2×10^{22} m
Diameter of our galaxy (the Milky Way)	1×10^{21} m
Distance from Earth to the nearest star (other than the Sun)	4×10^{16} m
One light-year	9.46×10^{15} m
Average radius of Pluto's orbit	6×10^{12} m
Distance from Earth to the Sun	1.5×10^{11} m
Radius of Earth	6.37×10^{6} m
Length of a football field	10^{2} m
Height of a person	2 m
Diameter of a CD	0.12 m
Diameter of the aorta	0.018 m
Diameter of a period in a sentence	5×10^{-4} m
Diameter of a red blood cell	8×10^{-6} m
Diameter of the hydrogen atom	10^{-10} m
Diameter of a proton	2×10^{-15} m

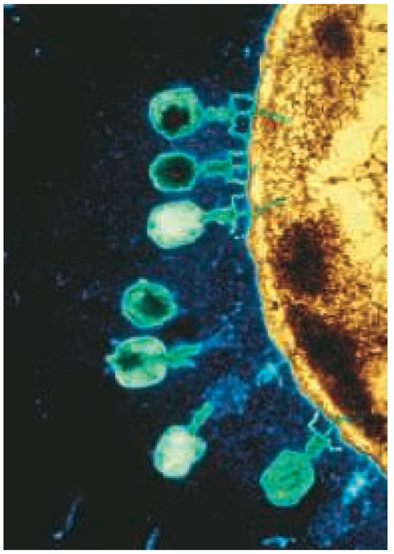
foot of King Louis XIV. As colorful as these units may be, they are not particularly reproducible—at least not to great precision.

In 1793 the French Academy of Sciences, seeking a more objective and reproducible standard, decided to define a unit of length equal to one ten-millionth the distance from the North Pole to the equator. This new unit was named the metre (from the Greek *metron* for "measure"). The preferred spelling in the United States is *meter*. This definition was widely accepted, and in 1799 a "standard" meter was produced. It consisted of a platinum-iridium alloy rod with two marks on it one meter apart.

Since 1983 we have used an even more precise definition of the meter, based on the speed of light in a vacuum:

> One meter is defined to be the distance traveled by light in a vacuum in 1/299,792,458 of a second.

No matter how its definition is refined, however, a meter is still about 3.28 feet, which is roughly 10 percent longer than a yard. A list of typical lengths is given in Table 1-1, and an illustration of the range of lengths is given in **FIGURE 1-1**.



(a)

(b)

▲ **FIGURE 1-1** **(a)** The size of these viruses, seen here attacking a bacterial cell, is about 10^{-7} m. **(b)** The diameter of this typical galaxy is about 10^{21} m. (How many viruses would it take to span the galaxy?)

Mass

In SI units, mass is measured in kilograms. Unlike the meter, the kilogram is not based on any natural physical quantity. By convention, the kilogram is defined as follows:

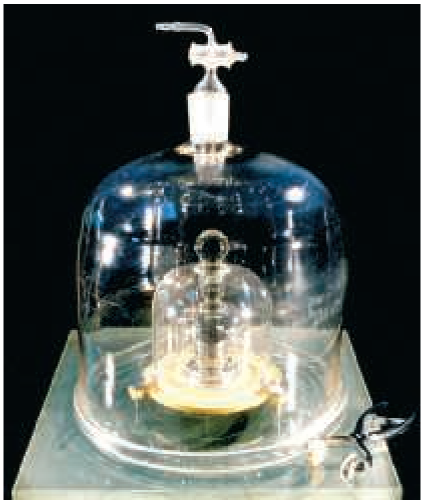
> The kilogram is the mass of a particular platinum-iridium alloy cylinder at the International Bureau of Weights and Measures in Sèvres, France. The cylinder, referred to as the standard kilogram, is shown in **FIGURE 1-2**.

To put the kilogram in everyday terms, a quart of milk has a mass slightly less than 1 kilogram. Additional masses, in kilograms, are given in Table 1-2.

It's important to note that we do not define the kilogram to be the *weight* of the platinum-iridium cylinder. In fact, weight and mass are quite different quantities, even though they are often confused in everyday language. Mass is an intrinsic, unchanging property of an object. Weight, in contrast, is a measure of the gravitational force acting on an object, which can vary depending on the object's location. For example, if you are fortunate enough to travel to Mars someday, you will find that your weight is less than on Earth, though your mass is unchanged. The force of gravity will be discussed in detail in Chapter 12.

TABLE 1-2 Typical Masses

Galaxy (Milky Way)	4×10^{41} kg
Sun	2×10^{30} kg
Earth	5.97×10^{24} kg
Space shuttle	2×10^{6} kg
Elephant	5400 kg
Automobile	1200 kg
Human	70 kg
Baseball	0.15 kg
Honeybee	1.5×10^{-4} kg
Red blood cell	10^{-13} kg
Bacterium	10^{-15} kg
Hydrogen atom	1.67×10^{-27} kg
Electron	9.11×10^{-31} kg



▲ **FIGURE 1-2** The standard kilogram, a cylinder of platinum and iridium 0.039 m in height and diameter, is kept under carefully controlled conditions in Sèvres, France. Exact replicas are maintained in other laboratories around the world.

Time

Nature has provided us with a fairly accurate timepiece in the revolving Earth. In fact, prior to 1956 the mean solar day was defined to consist of 24 hours, with 60 minutes per hour, and 60 seconds per minute, for a total of $(24)(60)(60) = 86{,}400$ seconds. Even the rotation of the Earth is not completely regular, however.

Today, the most accurate timekeepers are "atomic clocks," like the one in **FIGURE 1-3**, which are based on characteristic frequencies of radiation emitted by certain atoms. These clocks have typical accuracies of about 1 second in 6 million years. The atomic clock used for defining the second operates with cesium-133 atoms. In particular, the second is defined as follows:

> One second is defined to be the time it takes for radiation from a cesium-133 atom to complete 9,192,631,770 cycles of oscillation.

A range of characteristic time intervals is given in Table 1-3.

Atomic Clocks and Official Time The nation's time and frequency standard is determined by a *cesium fountain atomic clock* developed at the National Institute of Standards and Technology (NIST) in Boulder, Colorado. The fountain atomic clock, designated NIST-F2, produces a "fountain" of cesium atoms that are projected upward in a vacuum to a height of about a meter. It takes roughly a second for the atoms to rise and fall through this height (as we shall see in the next chapter), and during this relatively long period of time, the frequency of their oscillation can be measured with great precision. In fact, the NIST-F2 will gain or lose no more than one second in every 300 million years of operation.

Atomic clocks are almost commonplace these days. For example, the satellites that participate in the Global Positioning System (GPS) actually carry atomic clocks with them in orbit. This allows them to make the precise time measurements that are needed for an equally precise determination of a GPS user's position and speed. Similarly, the "atomic clocks" that are advertised for use in the home, while not atomic in their operation, nonetheless get their time from radio signals sent out from the atomic clocks at NIST in Boulder. You can access the official U.S. time on your computer by going to time.gov on the Web.

PHYSICS IN CONTEXT
Looking Ahead

The three physical dimensions introduced in this chapter—mass, length, and time—are the only ones we'll use until Chapter 16, when temperature is introduced. Other quantities found in the next several chapters, like force, momentum, and energy, are combinations of these three basic dimensions.

Other Systems of Units and Standard Prefixes

Although SI units are used throughout most of this book, and are used almost exclusively in scientific research and in industry, we will occasionally refer to other systems that you may encounter from time to time.

For example, a system of units similar to the mks system, though comprised of smaller units, is the **cgs system**, which stands for centimeter (cm), gram (g), and second (s). In addition, the British engineering system is often encountered in everyday usage in the United States. Its basic units are the slug for mass, the foot (ft) for length, and the second (s) for time.

Finally, multiples of the basic units are common no matter which system is used. Standard prefixes are used to designate common multiples in powers of ten. For example, the prefix *kilo* means one thousand, or, equivalently, 10^3. Thus, 1 kilogram is 10^3 grams, and 1 kilometer is 10^3 meters. Similarly, *milli* is the prefix for one thousandth, or 10^{-3}. Thus, a millimeter is 10^{-3} meter, and so on. The most common prefixes are listed in Table 1-4.

▲ **FIGURE 1-3** This atomic clock, which keeps time on the basis of radiation from cesium atoms, is accurate to about two ten-millionths of a second per year. (How much time would it take for it to gain or lose an hour?)

EXERCISE 1-1 CONVERTING UNITS

a. A baseball has a diameter of 75 millimeters. Give the diameter in meters and kilometers.

b. A house sells for 450,000 dollars. Express the price of the house in kilodollars and megadollars.

REASONING AND SOLUTION

Refer to Table 1-4 for a list of prefixes and their corresponding powers of ten.

a. 0.075 m, 0.000075 km

b. 450 kilodollars, 0.450 megadollars

Enhance Your Understanding (Answers given at the end of the chapter)

2. Rank the following lengths (A, B, C, and D) in order of increasing value. Indicate ties where appropriate. A = 2 millimeters; B = 10 micrometers; C = 0.1 kilometers; D = 10 centimeters.

Section Review

- The SI units of length, mass, and time are the meter, kilogram, and second, respectively.

TABLE 1-3 Typical Times

Age of the universe	4×10^{17} s
Age of the Earth	1.4×10^{17} s
Existence of human species	6×10^{12} s
Human lifetime	2×10^{9} s
One year	3×10^{7} s
One day	8.6×10^{4} s
Time between heartbeats	0.8 s
Human reaction time	0.1 s
One cycle of a high-pitched sound wave	5×10^{-5} s
One cycle of an AM radio wave	10^{-6} s
One cycle of a visible light wave	2×10^{-15} s

1-3 Dimensional Analysis

In physics, when we speak of the **dimension** of a physical quantity, we refer to the *type* of quantity in question, regardless of the units used in the measurement. For example, a distance measured in cubits and another distance measured in light-years both have the same dimension—length. The same is true of compound units such as velocity, which has the dimensions of length per unit time (length/time). A velocity measured in miles per hour has the same dimensions—length/time—as a velocity measured in inches per century.

Now, any valid formula in physics must be **dimensionally consistent**; that is, each term in the equation must have the same dimensions. It simply doesn't make sense to add a distance to a time, for example, any more than it makes sense to add apples and oranges. They are different things.

Checking Dimensional Consistency and Dimensional Analysis To check the dimensional consistency of an equation, it's convenient to introduce a special notation for the dimension of a quantity. We will use square brackets, [ ], for this purpose. Thus, if x represents a distance, which has dimensions of length [L], we write this as $x = [\mathrm{L}]$. Similarly, a velocity, v, has dimensions of length [L] per time [T]; thus we write $v = [\mathrm{L}]/[\mathrm{T}]$ to indicate its dimensions. Acceleration, a, which is the change in velocity per time, has the dimensions $a = ([\mathrm{L}]/[\mathrm{T}])/[\mathrm{T}] = [\mathrm{L}]/[\mathrm{T}^2]$. The dimensions of some common physical quantities are listed in Table 1-5.

Let's use this notation to check the dimensional consistency of a simple equation. Consider the following formula:

$$x = x_0 + vt$$

In this equation, x and x_0 represent distances, v is a velocity, and t is time. Writing out the dimensions of each term, we have

$$[\mathrm{L}] = [\mathrm{L}] + \frac{[\mathrm{L}]}{[\mathrm{T}]}[\mathrm{T}]$$

It might seem that the last term has different dimensions than the other two. However, dimensions obey the same rules of algebra as other quantities. Thus the dimensions of time cancel in the last term:

$$[\mathrm{L}] = [\mathrm{L}] + \frac{[\mathrm{L}]}{[\cancel{\mathrm{T}}]}[\cancel{\mathrm{T}}] = [\mathrm{L}] + [\mathrm{L}]$$

As a result, we see that each term in this formula has the same dimension, [L]. This type of calculation with dimensions is referred to as **dimensional analysis**.

TABLE 1-4 Common Prefixes

Power	Prefix	Abbreviation
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{1}	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f

Big Idea 3 Valid equations in physics must be dimensionally consistent. This means that each term in the equation must have the same dimensions.

EXERCISE 1-2 ANALYZING DIMENSIONS

Show that $x = x_0 + v_0t + \frac{1}{2}at^2$ is dimensionally consistent. The quantities x and x_0 are distances, v_0 is a velocity, and a is an acceleration.

CONTINUED

TABLE 1-5 Dimensions of Some Common Physical Quantities

Quantity	Dimension
Distance	[L]
Area	[L^2]
Volume	[L^3]
Velocity	[L]/[T]
Acceleration	[L]/[T^2]
Energy	[M][L^2]/[T^2]

PHYSICS IN CONTEXT
Looking Ahead

Dimensional analysis is used frequently in the coming chapters to verify that each term in an equation has the correct dimensions. We will also use dimensional analysis to help derive some results, such as the speed of waves on a string in Chapter 14.

REASONING AND SOLUTION

Use the dimensions given in Table 1-5 for each term in the equation. Cancel dimensions where appropriate.

$$\text{Original equation:} \quad x = x_0 + v_0 t + \tfrac{1}{2}at^2$$

$$\text{Dimensions:} \quad [\mathrm{L}] = [\mathrm{L}] + \frac{[\mathrm{L}]}{[\cancel{\mathrm{T}}]}[\cancel{\mathrm{T}}] + \frac{[\mathrm{L}]}{[\cancel{\mathrm{T}^2}]}[\cancel{\mathrm{T}^2}] = [\mathrm{L}] + [\mathrm{L}] + [\mathrm{L}]$$

Notice that $\frac{1}{2}$ is ignored in this analysis because it is simply a numerical factor, and has no dimensions.

Later in this text you will derive your own formulas from time to time. As you do so, it is helpful to check dimensional consistency at each step of the derivation. If at any time the dimensions don't agree, you will know that a mistake has been made, and you can go back and look for it. If the dimensions check, however, it's not a guarantee the formula is correct—after all, dimensionless numerical factors, like $\frac{1}{2}$ or 2, don't show up in a dimensional check.

Enhance Your Understanding (Answers given at the end of the chapter)

3. Give the dimensions of each of the following quantities (A, B, C, D), given that x is a distance, v is a velocity, a is an acceleration, and t is a time. A $= at$; B $= v/t$; C $= 0.5x/t^2$; D $= 2ax$.

Section Review

- The dimension of a quantity is the type of quantity it is—such as length, mass, or time.
- Each term in a valid physics equation must have the same dimensions.

▲ **FIGURE 1-4** Every measurement has some degree of uncertainty associated with it. How precise would you expect this measurement to be?

1-4 Significant Figures, Scientific Notation, and Round-Off Error

In this section we discuss a few issues regarding the numerical values that arise in scientific measurements and calculations.

Significant Figures

When a length, a mass, or a time is measured in a scientific experiment, the result is known only to within a certain accuracy. The inaccuracy or uncertainty can be caused by a number of factors, as illustrated in **FIGURE 1-4**, ranging from limitations of the measuring device itself to limitations associated with the senses and the skill of the person performing the experiment. In any case, the fact that observed values of experimental quantities have inherent uncertainties should always be kept in mind when performing calculations with those values.

The level of uncertainty in a numerical value is indicated by the number of **significant figures** it contains. We define significant figures as follows:

Number of Significant Figures
The number of significant figures ("sig figs" for short) in a physical quantity is equal to the number of digits in it that are known with certainty.

As an example, suppose you want to determine the walking speed of your pet tortoise. To do so, you measure the time, t, it takes for the tortoise to walk a distance, d, and then you calculate the quotient, d/t. When you measure the distance with a ruler, which has one tick mark per millimeter, you find that $d = 21.4$ cm. Each of these three digits is known with certainty, though the digit that follows the 4 is uncertain. Hence, we say that d has *three* significant figures. Similarly, you measure the time with an old pocket watch, and determine that $t = 8.5$ s. It follows that t is known to only *two* significant figures, because you are not certain of the digit that follows the 5.

We would now like to calculate the speed of the tortoise. Using the above values for d and t, and a calculator with eight digits in its display, we find $(21.4 \text{ cm})/(8.5 \text{ s}) = 2.5176470 \text{ cm/s}$. Clearly, such an accurate value for the speed is unjustified, considering the limitations of our measurements. In general, the number of significant figures that result when we multiply or divide physical quantities is given by the following rule of thumb:

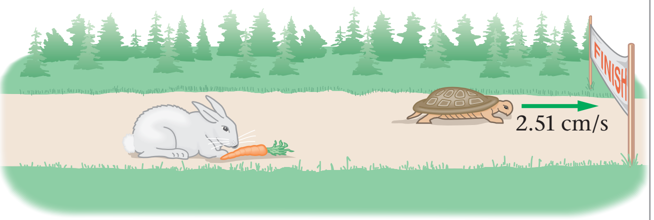
Significant Figures When Multiplying or Dividing
The number of significant figures after multiplication or division is equal to the number of significant figures in the *least* accurately known quantity.

In our speed calculation, for example, we know the distance to three significant figures, but we know the time to only two significant figures. As a result, the speed should be given with just two significant figures: $d/t = (21.4 \text{ cm})/(8.5 \text{ s}) = 2.5 \text{ cm/s}$. Thus, 2.5 cm/s is our best estimate for the tortoise's speed, given the uncertainty in our measurements.

EXAMPLE 1-3 IT'S THE TORTOISE BY A HARE

A tortoise races a rabbit by walking with a constant speed of 2.51 cm/s for 12.27 s. How much distance does the tortoise cover?

PICTURE THE PROBLEM
The race between the rabbit and the tortoise is shown in our sketch. The rabbit pauses to eat a carrot while the tortoise walks with a constant speed.



REASONING AND STRATEGY
The distance covered by the tortoise is the speed of the tortoise multiplied by the time during which it walks.

Known Constant speed = 2.51 cm/s; walking time = 12.27 s.
Unknown Distance, $d = ?$

SOLUTION

1. Multiply the speed by the time to find the distance d:

$$d = (\text{speed})(\text{time}) = (2.51 \text{ cm/s})(12.27 \text{ s}) = 30.8 \text{ cm}$$

INSIGHT
If we simply multiply 2.51 cm/s by 12.27 s, we obtain 30.7977 cm. We don't give all of these digits in our answer, however. In particular, because the quantity that is known with the least accuracy (the speed) has only three significant figures, we give a result with three significant figures. In addition, notice that the third digit in our answer has been rounded up from 7 to 8 because the number that follows 7 is greater than or equal to 5.

PRACTICE PROBLEM
How much time does it take for the tortoise to walk 17 cm? [**Answer:** $t = (17 \text{ cm})/(2.51 \text{ cm/s}) = 6.8 \text{ s}$]

Some related homework problems: Problem 14, Problem 18

The distance of 17 cm in the above Practice Problem has only two significant figures, because we don't know the digits to the right of the decimal place. If the distance were given as 17.0 cm, on the other hand, it would have three significant figures. The role of significant figures in a real-world situation is illustrated in **FIGURE 1-5**.

When physical quantities are added or subtracted, we use a slightly different rule of thumb. In this case, the rule involves the number of decimal places in each of the terms:

Significant Figures When Adding or Subtracting
The number of decimal places after addition or subtraction is equal to the smallest number of decimal places in any of the individual terms.

▲ **FIGURE 1-5** The time measurements for a race like this must be accurate to several significant figures. This level of accuracy is needed to determine both the winning time, and the order in which the other runners finished.

Thus, if you make a time measurement of 16.74 s and then a subsequent time measurement of 5.1 s, the total time of the two measurements should be given as 16.74 s + 5.1 s = 21.8 s, rather than 21.84 s.

EXERCISE 1-4 FINDING THE TOTAL WEIGHT

You and a friend go fishing. You catch a fish that weighs 10.7 lb, and your friend catches a fish that weighs 8.35 lb. What is the combined weight of the two fish?

REASONING AND SOLUTION

Simply adding the two numbers gives 19.05 lb. According to our rule of thumb, however, the final result must have only a single decimal place (corresponding to the term with the smallest number of decimal places). Rounding off to one decimal place, then, gives 19.1 lb as the accepted result.

Scientific Notation

The number of significant figures in a given quantity may be ambiguous due to the presence of zeros at the beginning or end of the number. For example, if a distance is stated to be 2500 m, the two zeros could be significant figures, or they could be zeros that simply show where the decimal point is located. If the two zeros are significant figures, the uncertainty in the distance is roughly a meter; if they are not significant figures, however, the uncertainty is about 100 m.

To remove this type of ambiguity, we can write the distance in **scientific notation**—that is, as a number of order unity times an appropriate power of ten. Thus, in this example, we would express the distance as 2.5×10^3 m if there are only two significant figures, or as 2.500×10^3 m to indicate four significant figures. Likewise, a time given as 0.000036 s has only two significant figures—the preceding zeros only serve to fix the decimal point. If this quantity were known to three significant figures, we would write it as 0.0000360 s, or equivalently as 3.60×10^{-5} s, to remove any ambiguity. See Appendix A for a more detailed discussion of scientific notation.

EXERCISE 1-5 SIGNIFICANT FIGURES

How many significant figures are there in **(a)** 0.0210, **(b)** 5.060, **(c)** 7.10×10^{-4}, **(d)** 1.0×10^5?

REASONING AND SOLUTION

Preceding zeros don't count when determining the number of significant figures, but trailing zeros and zeros within a number do count. As a result, the number of significant figures is as follows: **(a)** 3, **(b)** 4, **(c)** 3, **(d)** 2.

Round-Off Error

Finally, even if you perform all your calculations to the same number of significant figures as in the text, you may occasionally obtain an answer that differs in its last digit from that given in the book. In most cases this is not an issue as far as understanding the physics is concerned—usually it is due to **round-off error**.

Round-off error occurs when numerical results are rounded off at different times during a calculation. To see how this works, let's consider a simple example. Suppose you are shopping for knickknacks, and you buy one item for \$2.21, plus 8 percent sales tax. The total price is \$2.3868 or, rounded off to the nearest penny, \$2.39. Later, you buy another item for \$1.35. With tax this becomes \$1.458 or, again to the nearest penny, \$1.46. The total expenditure for these two items is \$2.39 + \$1.46 = \$3.85.

Now, let's do the rounding off in a different way. Suppose you buy both items at the same time for a total before-tax price of \$2.21 + \$1.35 = \$3.56. Adding in the 8 percent tax gives \$3.8448, which rounds off to \$3.84, one penny different from the previous amount. This type of discrepancy can also occur in physics problems. In general, it's a good idea to keep one extra digit throughout your calculations whenever possible, rounding off only the final result. But, while this practice can help to reduce the likelihood of round-off error, there is no way to avoid it in every situation.

Enhance Your Understanding

(Answers given at the end of the chapter)

4. Rank the following numbers in order of increasing number of significant figures. Indicate ties where appropriate. A = 1; B = 1001; C = 10.01; D = 123.

Section Review

- The number of significant figures in a physical quantity is the number of digits known with certainty. The greater the number of significant figures, the more accurately the quantity is known.
- Round-off error occurs when numbers are rounded off at different points in a calculation. The small discrepancy that results is not significant.

1-5 Converting Units

It's often convenient to convert from one set of units to another. For example, suppose you want to convert 316 ft to its equivalent in meters. Looking at the conversion factors on the inside front cover of the text, we see that

$$1\ \mathrm{m} = 3.281\ \mathrm{ft}$$

Equivalently,

$$\frac{1\ \mathrm{m}}{3.281\ \mathrm{ft}} = 1$$

Now, to make the conversion, we simply multiply 316 ft by this expression, which is equivalent to multiplying by 1:

$$(316\ \cancel{\mathrm{ft}})\left(\frac{1\ \mathrm{m}}{3.281\ \cancel{\mathrm{ft}}}\right) = 96.3\ \mathrm{m}$$

We write the conversion factor in this particular way, as 1 m divided by 3.281 ft, so that the units of feet cancel out, leaving the final result in the desired units of meters.

Of course, we can just as easily convert from meters to feet if we use the reciprocal of this conversion factor—which is also equal to 1:

$$1 = \frac{3.281\ \mathrm{ft}}{1\ \mathrm{m}}$$

For example, a distance of 26.4 m is converted to feet by canceling out the units of meters, as follows:

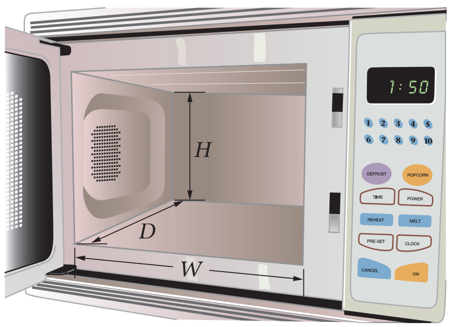
$$(26.4\ \cancel{\mathrm{m}})\left(\frac{3.281\ \mathrm{ft}}{1\ \cancel{\mathrm{m}}}\right) = 86.6\ \mathrm{ft}$$

Thus, we see that converting units is as easy as multiplying by 1—because that's really what you're doing. A real-world example of unit conversion is shown in **FIGURE 1-6**.

▲ **FIGURE 1-6** From this sign, you can calculate factors for converting miles to kilometers and vice versa. (Why do you think the conversion factors seem to vary for different destinations?)

EXAMPLE 1-6 A HIGH-VOLUME ITEM

The interior of a popular microwave oven has a width $W = 15.5$ in., a depth $D = 14.5$ in., and a height $H = 9.25$ in. What is the interior volume of the oven in SI units?



PICTURE THE PROBLEM

In our sketch we picture the oven, and indicate the dimensions given in the problem statement.

REASONING AND STRATEGY

We begin by converting the width, depth, and height of the oven to meters. Once this is done, the volume in SI units is simply the product of the three dimensions.

CONTINUED