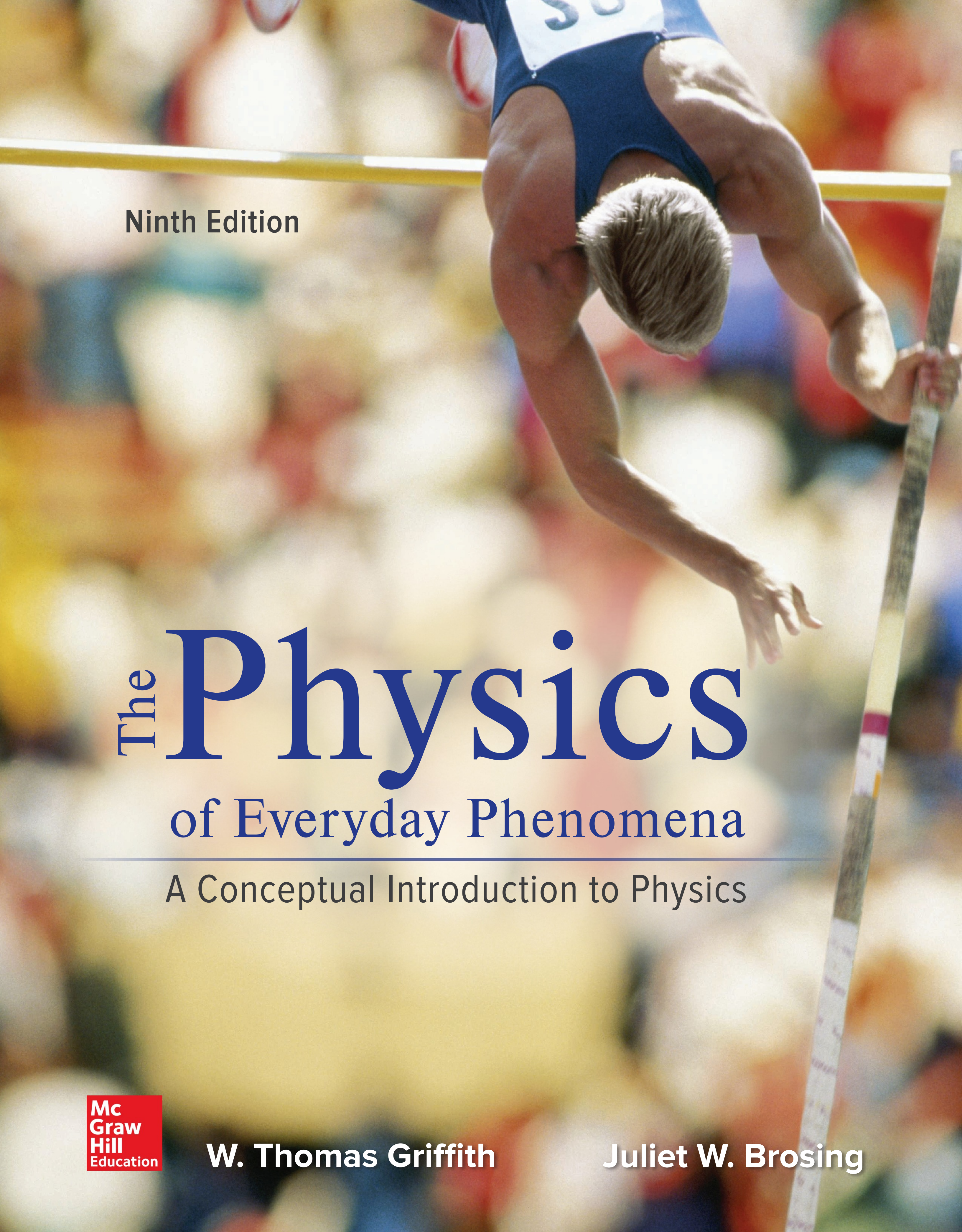


Ninth Edition

# The Physics of Everyday Phenomena

## A Conceptual Introduction to Physics

McGraw Hill Education

W. Thomas Griffith

Juliet W. Brosing

Ninth Edition

# The Physics of Everyday Phenomena

## A Conceptual Introduction to Physics

**W. Thomas Griffith**
Pacific University

**Juliet W. Brosing**
Pacific University

McGraw Hill Education

THE PHYSICS OF EVERYDAY PHENOMENA: A CONCEPTUAL INTRODUCTION TO PHYSICS, NINTH EDITION

Published by McGraw-Hill Education, 2 Penn Plaza, New York, NY 10121. 

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 LWI 21 20 19 18

ISBN 978-1-259-89400-8
MHID 1-259-89400-2

Sr. Portfolio Manager: *Thomas M. Scaife, Ph.D.*
Product Developer: *Jolynn Kilburg*
Marketing Manager: *Shannon O'Donnell*
Sr. Content Project Managers: *Sherry Kane / Tammy Juran*
Buyer: *Susan K. Culbertson*
Design: *Matt Backhaus*
Content Licensing Specialist: *Beth Thole*
Cover Image: ©*Dennis O'Clair/Getty Images*
Compositor: *Aptara®, Inc.*

All credits appearing on page or at the end of the book are considered to be an extension of the copyright page.

**Library of Congress Cataloging-in-Publication Data**

Names: Griffith, W. Thomas, author. | Brosing, Juliet Wain, 1953- author.
Title: The physics of everyday phenomena : a conceptual introduction to physics / W. Thomas Griffith (Pacific University), Juliet W. Brosing (Pacific University).
Description: Ninth edition. | New York, NY : McGraw-Hill Education, 2019.
Identifiers: LCCN 2017023968 | ISBN 9781259894008 (alk. paper) | ISBN 1259894002 (alk. paper)
Subjects: LCSH: Physics—Textbooks.
Classification: LCC QC23.2 .G75 2019 | DDC 530—dc23 LC record available at https://lccn.loc.gov/2017023968



mheducation.com/highered

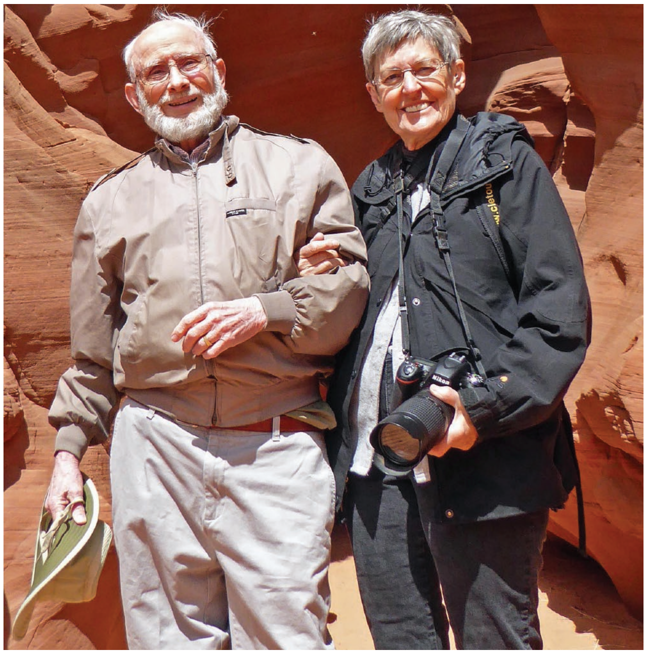
# Brief Contents



Mc Graw Hill Education
5011333

# About the Authors

Tom Griffith is now Distinguished University Professor Emeritus at Pacific University in Forest Grove, Oregon, having retired after 36 years of teaching physics at Pacific. He still shows up on campus on occasion and might make a rare appearance with his guitar in a physics course. He now spends half of the year in Portland, Oregon, and his winters in Green Valley, Arizona. Over the years he has enjoyed hiking, bicycling, singing, and participating in musical comedies, and he still performs in a jam band in Arizona. During his years at Pacific, he served as Physics Department Chair, Natural Sciences Division Chair, Interim Dean of Enrollment Management, and Director of Institutional Research, among other things, but his primary focus was always teaching physics. He was active in the American Association of Physics Teachers (AAPT), and the Northwest Association for College Physics (PNACP). His wife of 42 years, Adelia, died of cancer in 2009. He married his wife, Sally, an art photographer, in 2014 and they both enjoy exploring the western United States and more distant places.



The author and his wife, Sally, exploring Antelope Canyon in Arizona.
*Courtesy of Tom Griffith*

Juliet Brosing, Professor of Physics at Pacific University in Forest Grove, Oregon, has taught there for 30 years. Her research interests include nuclear physics, medical physics, and the application of teaching methods grounded in physics' educational research. She has supported the importance of attracting young women into careers in science by helping to plan and run summer camps for seventh- and eighth-grade girls, during the past 30 years. In 2012 she was named Oregon Professor of the Year by the Carnegie Foundation for the Advancement of Teaching and CASE (the Council for Advancement and Support of Education). She is the proud owner of three potato guns; parties with students at her house usually involve projectiles, lots of noise, and fudge. She remains active in both the state and national American Association of Physics Teachers (AAPT) and the Pacific Northwest Association for College Physics (PNACP). Above all, Dr. Brosing is dedicated to teaching physics with a positive outlook and methods that encourage and benefit her students, regardless of their chosen field of study.

The author, Juliet Brosing, and her husband Keith LeComte at the Tualatin River near their home in Cherry Grove, Oregon.
*Courtesy of Kristin Larkins*

# Detailed Contents

# Preface

The satisfaction of understanding how rainbows are formed, how ice skaters spin, or why ocean tides roll in and out—phenomena that we have all seen or experienced—is one of the best motivators available for building scientific literacy. This book attempts to make that sense of satisfaction accessible to non-science majors. Intended for use in a one-semester or two-quarter course in conceptual physics, this book is written in a narrative style, frequently using questions designed to draw the reader into a dialogue about the ideas of physics. This inclusive style allows the book to be used by anyone interested in exploring the nature of physics and explanations of everyday physical phenomena.

> *"The origin of the book came from an effort to write usable conceptual questions. The concepts are what we hope non-science majors will carry with them. Quantitative exercises have their place, but should be subordinate to the concepts."*
>
> —W. Thomas Griffith, Author

## How This Book Is Organized

The organization of chapters is traditional with some minor variations. The chapter on energy (chapter 6) appears prior to that on momentum (chapter 7) so that energy ideas can be used in the discussion of collisions. Wave motion is found in chapter 15, following electricity and magnetism and prior to chapters 16 and 17 on optics. The chapter on fluids (chapter 9) follows mechanics and leads into the chapters on thermodynamics. The first 17 chapters are designed to introduce students to the major ideas of classical physics and can be covered in a one-semester course with some judicious paring.

The complete 21 chapters could easily support a two-quarter course, and even a two-semester course in which the ideas are treated thoroughly and carefully. Chapters 18 and 19, on atomic and nuclear phenomena, are considered essential by many instructors, even in a one-semester course. If included in such a course, we recommend curtailing coverage in other areas to avoid student overload. Sample syllabi for these different types of courses can be found on the instructor's website.

Some instructors would prefer to put chapter 20 on relativity at the end of the mechanics section or just prior to the modern physics material. Relativity has little to do with everyday phenomena, of course, but is included because of the high interest that it generally holds for students. The final chapter (21) introduces a variety of topics in modern physics—including particle physics, cosmology, semiconductors, and superconductivity—that could be used to stimulate interest at various points in a course.

One plea to instructors, as well as to students using this book: Don't try to cram too much material into too short a time! We have worked diligently to keep this book to a reasonable length while still covering the core concepts usually found in an introduction to physics. These ideas are most enjoyable when enough time is spent in lively discussion and in consideration of questions so that a real understanding develops. Trying to cover material too quickly defeats the conceptual learning and leaves students in a dense haze of words and definitions. Less can be more if a good understanding results.

## Mathematics in a Conceptual Physics Course

The use of mathematics in a physics course is a formidable block for many students, particularly non-science majors. Although there have been attempts to teach conceptual physics without any mathematics, these attempts miss an opportunity to help students gain confidence in using and manipulating simple quantitative relationships.

Clearly mathematics is a powerful tool for expressing the quantitative relationships of physics. The use of mathematics can be carefully limited, however, and subordinated to the physical concepts being addressed. Many users of the first edition of this text felt that mathematical expressions appeared too frequently for the comfort of some students. In response, we substantially reduced the use of mathematics in the body of the text in the second edition. Most users have indicated that the current level is about right, so we have not changed the mathematics level in subsequent editions.

Logical coherence is a strong feature of this book. Formulas are introduced carefully after conceptual arguments are provided, and statements in words of these relationships generally accompany their introduction. We have continued to fine tune the example boxes that present sample exercises and questions. Most of these provide simple numerical illustrations of the ideas discussed. No mathematics prerequisite beyond high school algebra should be necessary. A discussion of the basic ideas of very simple algebra is found in appendix A, together with some practice exercises, for students who need help with these ideas.

## New to This Edition

Building upon the existing strengths of *The Physics of Everyday Phenomena* text, we have made additions to our offerings based on reviewer feedback. The most significant changes in this edition have come with the digital enhancements.

- We have added to our Connect® offerings by building additional videos narrated by one of the authors that explain how physics is involved in everyday situations. (These videos are noted in text with an icon)
- We have developed additional conceptual questions and made them available as online homework.
- Significant effort has been invested in making the links in the e-book more useful and informative.
- The use of Connect and SmartBook will greatly enhance your students' understanding and minimize your work load.
- We have worked hard to improve the PowerPoint lectures and clicker questions so a faculty member can prepare for an engaged class period with a minimum of effort.
- The test bank is more robust, both in terms of the software package and the caliber of the questions.

In addition to the enhanced digital offerings, we have continued to improve upon the text with the ninth edition. As the book has evolved, we have tried to remain faithful to the principles that have guided the writing of the book from the outset. One of these has been to keep the book to a manageable length, in both the number of chapters and the overall content.

We have revised and updated the end of chapter problems in the text. Additionally, we have changed almost all the exercise numbers in this edition. A file on the companion website maps the problems from the 8th edition to the 9th edition, to help those who have developed solutions for their students. All odd numbered exercises have the answers in appendix D in the hard copy of the text, and links to the answers in the e-book. Answers to about one-sixth of the conceptual questions are also included. We encourage users to adopt the digital homework system, Connect. The value of this is that for the exercises, each student has slightly different numbers. Thus, they discuss HOW to do the problem with each other, not what is the answer. We have found this to be very powerful pedagogically. We have worked hard to reword the conceptual questions as multiple choice offerings in Connect. This can be a significant tool to enhance conceptual understanding.

The example boxes have been praised by many users. As many of the students whom use this book are somewhat math phobic, we strive to make the example boxes helpful and clear. Every edition we make improvements in these boxes. In chapter 8, a new example box has been added, helping students understand how to convert from revolutions per minute to radians per second.

In addition to these specific changes, we have also revised the text in many places to enhance understanding of some of the more difficult concepts.

**Building an Energy Emphasis.** Although this book remains a basic conceptual physics text, we are working to make the book better serve instructors who want to teach a conceptual physics course with an energy emphasis. A syllabus for instructors wishing to teach a course with an energy emphasis can be found on the companion website. We plan to continue building this emphasis in future editions.

**Continued Refinements in Artwork and Textual Clarity.** Although the textual clarity of this text has been extensively praised by many reviewers and users, it can always be improved. Reviewers continue to point out places where either the art or the text can be improved, and we have responded to many of these suggestions. To this end, we have made many changes, often subtle, to both the art and the text.

## Digital Learning Tools

### Connect

McGraw-Hill Connect® is a highly reliable, easy-to use homework and learning management solution that utilizes learning science and award winning adaptive tools to improve student results.

### Homework and Adaptive Learning

- Connect's assignments help students contextualize what they've learned through application, so they can better understand the material and think critically.
- Connect will create a personalized study path customized to individual student needs through SmartBook®.
- SmartBook helps students study more efficiently by delivering an interactive reading experience through adaptive highlighting and review.

### Robust Analytics and Reporting

Connect Insight® generates easy-to-read reports on individual students, the class as a whole, and on specific assignments.

- The Connect Insight dashboard delivers data on performance, study behavior, and effort. Instructors can quickly identify students who struggle and focus on material that the class has yet to master.
- Connect automatically grades assignments and quizzes, providing easy-to-read reports on individual and class performance.

### Trusted Service and Support

Connect integrates with your Leaning Management System (LMS) to provide single sign-on and automatic syncing of grades. Integration with Blackboard®, D2L®, Moodle, and Canvas also provides automatic syncing of the course calendar and assignment-level linking.

- Connect offers comprehensive service, support, and training throughout every phase of your implementation.
- If you're looking for some guidance on how to use Connect, or want to learn tips and tricks from super users, you can find tutorials as you work. Our Digital Faculty Consultants and Student Ambassadors offer insight into how to achieve the results you want with Connect.

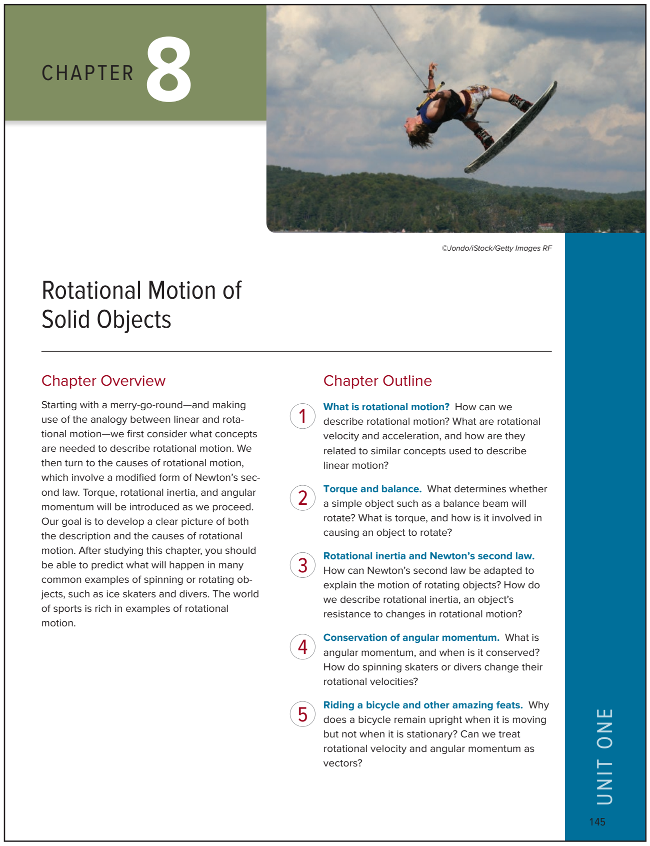
## Learning Aids

The overriding theme of this book is to introduce physical concepts by appealing to everyday phenomena whenever possible. To achieve this goal, this text includes a variety of features to make the study of *The Physics of Everyday Phenomena* more effective and enjoyable. A few key concepts form the basis for understanding physics, and the textual features described here reinforce this structure so that the reader will not be lost in a flurry of definitions and formulas.

### Chapter Openers

Each chapter begins with an illustration from everyday experience and then proceeds to use it as a theme for introducing relevant physical concepts. Physics can seem abstract to many students, but using everyday phenomena and concrete examples reduces that abstractness. The chapter **overview** previews the chapter's contents and what students can expect to learn from reading the chapter. The overview introduces the concepts to be covered, facilitating the integration of topics, and helping students to stay focused and organized while reading the chapter for the first time. The chapter **outline** includes all the major topic headings within the body of the chapter. It also contains questions that provide students with a guide of what they will be expected to know in order to comprehend the major concepts of the chapter. (These questions are then correlated to the end-of-chapter summaries.)

The chapter outlines, questions, and summaries provide a clear framework for the ideas discussed in each chapter. One of the difficulties that students have in learning physics (or any subject) is that they fail to construct the big picture of how things fit together. A consistent chapter framework can be a powerful tool in helping students see how ideas mesh.


CHAPTER 8

©Jondo/iStock/Getty Images RF

Rotational Motion of Solid Objects

Chapter Overview

Starting with a merry-go-round—and making use of the analogy between linear and rotational motion—we first consider what concepts are needed to describe rotational motion. We then turn to the causes of rotational motion, which involve a modified form of Newton's second law. Torque, rotational inertia, and angular momentum will be introduced as we proceed. Our goal is to develop a clear picture of both the description and the causes of rotational motion. After studying this chapter, you should be able to predict what will happen in many common examples of spinning or rotating objects, such as ice skaters and divers. The world of sports is rich in examples of rotational motion.

Chapter Outline

1. **What is rotational motion?** How can we describe rotational motion? What are rotational velocity and acceleration, and how are they related to similar concepts used to describe linear motion?
2. **Torque and balance.** What determines whether a simple object such as a balance beam will rotate? What is torque, and how is it involved in causing an object to rotate?
3. **Rotational inertia and Newton's second law.** How can Newton's second law be adapted to explain the motion of rotating objects? How do we describe rotational inertia, an object's resistance to changes in rotational motion?
4. **Conservation of angular momentum.** What is angular momentum, and when is it conserved? How do spinning skaters or divers change their rotational velocities?
5. **Riding a bicycle and other amazing feats.** Why does a bicycle remain upright when it is moving but not when it is stationary? Can we treat rotational velocity and angular momentum as vectors?

UNIT ONE

145

### Other Text Features

**Running summary paragraphs** are found at the end of each chapter section to supplement the more general summary at the end of the chapter.

> Light rays are bent when they pass from one transparent substance to another because the speed of light changes at the boundary between the two substances. The law of refraction describes how much bending occurs and whether the bending is toward or away from the surface normal. Because of this bending, the image of an underwater object appears to lie closer to the surface of the water than the actual position of the object. For light traveling initially inside glass or water, there is a critical angle of incidence beyond which the light is totally reflected rather than being refracted. The index of refraction varies with wavelength, producing the dispersion of colors we see when light passes through a prism.

**Subsection headings** are often cast in the form of questions to motivate the reader and pique curiosity.

> **What happens if the curve is banked?**
>
> If the road surface is properly banked, we are no longer totally dependent on friction to produce the centripetal acceleration. For the banked curve, the normal force between the car's tires and the road surface can also be helpful (fig. 5.8). As discussed in chapter 4, the **normal force, N,** is always perpendicular to the surfaces involved, so it points in the direction shown in the diagram. The total normal force acting on the car (indicated in the diagram) is the sum of those for each of the four tires.
>
> Because the car is not accelerated vertically, the net force in the vertical direction must be zero. The vertical compo-

**Everyday phenomenon boxes** relate physical concepts discussed in the text to real-world topics, societal issues, and modern technology, underscoring the relevance of physics and how it relates to our day-to-day lives. The list of topics includes

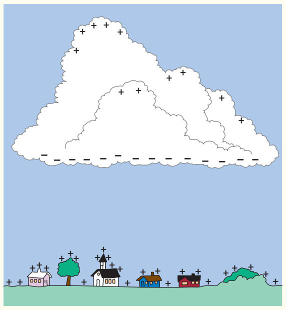
- The Case of the Malfunctioning Coffee Pot (chapter 1)
- Transitions in Traffic Flow (chapter 2)
- The 100-m Dash (chapter 2)
- Reaction Time (chapter 3)
- Shooting a Basketball (chapter 3)
- The Tablecloth Trick (chapter 4)
- Riding an Elevator (chapter 4)
- Seat Belts, Air Bags, and Accident Dynamics (chapter 5)
- Explaining the Tides (chapter 5)
- Conservation of Energy (chapter 6)
- Energy and the Pole Vault (chapter 6)
- The Egg Toss (chapter 7)
- An Automobile Collision (chapter 7)
- Achieving the State of Yo (chapter 8)
- Bicycle Gears (chapter 8)
- Measuring Blood Pressure (chapter 9)
- Throwing a Curveball (chapter 9)
- Heat Packs (chapter 10)
- Solar Collectors and the Greenhouse Effect (chapter 10)
- Hybrid Automobile Engines (chapter 11)
- A Productive Pond (chapter 11)
- Cleaning Up the Smoke (chapter 12)
- Lightning (chapter 12)
- Electrical Impulses in Nerve Cells (chapter 13)
- The Hidden Switch in Your Toaster (chapter 13)
- Direct-Current Motors (chapter 14)
- Vehicle Sensors at Traffic Lights (chapter 14)
- Electric Power from Waves (chapter 15)
- A Moving Car Horn and the Doppler Effect (chapter 15)
- Why Is the Sky Blue? (chapter 16)
- Antireflection Coatings on Eyeglasses (chapter 16)
- Rainbows (chapter 17)
- Laser Refractive Surgery (chapter 17)
- Fuel Cells and the Hydrogen Economy (chapter 18)
- Electrons and Television (chapter 18)
- Smoke Detectors (chapter 19)
- What Happened at Fukushima? (chapter 19)
- The Twin Paradox (chapter 20)
- Holograms (chapter 21)

**Everyday Phenomenon** **Box 12.2**

**Lightning**

**The Situation.** We have all observed the awe-inspiring beauty and power of a good electrical storm. The flashes of lightning, followed at varying time intervals by claps of thunder, can be both fascinating and frightening. What is lightning? How are thunderclouds capable of producing the impressive electrical discharges we see? What happens in an electrical storm?

Flashes of lightning illuminate the area. What is lightning, and how is it produced? *©Thomas Allen/Getty Images RF*




The charge distribution within a thundercloud induces a positive charge on objects on the Earth directly below the cloud.

**The Analysis.** Most thunderclouds generate a separation of charge within the cloud that produces a net positive charge near the top of the cloud and a net negative charge near the bottom. Highly turbulent convection taking place in the cloud separates and transports the charge: Thunderclouds consist of rapidly rising and falling columns of air and water, with cells of rising air often being found next to cells of falling air and water.

Earth below the cloud due to the negative charge on the bottom of the cloud.

The electric field generated by this charge distribution (pictured in the drawing) can be several thousand volts per meter. Because the base of the cloud usually floats several hundred meters above the Earth's surface, the potential difference between the cloud's base and the Earth can easily be several million volts! (Even during fair weather, there is an electric field

**Study hints** and **study suggestions** provide students with pointers on their use of the textbook, tips on applying the principles of physical concepts, and suggestions for home experiments.

## Study Hint

If you have the materials handy, you should try the battery-and-bulb experiment before reading further. The delight of figuring out how to get the bulb to light is something not to be spoiled by reading on prematurely. Once you get it to light (without, we hope, killing the battery), you may wish to experiment with other configurations and try to understand what distinguishes working arrangements from nonworking ones. Experimenting will help to make the concept of a circuit more vivid.

**Example boxes** are included within the chapter and contain one or more concrete, worked examples of a problem and its solution as it applies to the topic at hand. Through careful study of these examples, students can better appreciate the many uses of problem solving in physics.

## Example Box 6.1

**Sample Exercise: How Much Work?**

A crate is pulled a distance of 4 m across the floor under the influence of a 50-N force applied by a rope to the crate. What is the work done on the crate by the 50-N force if:

a. the rope is horizontal, parallel to the floor?
b. the rope pulls at an angle to the floor, so that the horizontal component of the 50-N force is 30 N (fig. 6.6)?

**a.** $F = 50\text{ N}$ $\quad W = Fd$

$d = 4\text{ m}$ $\quad = (50\text{ N})(4\text{ m})$

$W = ?$ $\quad = \mathbf{200\ J}$

**Debatable Issues** provide open-ended, opinion questions on—but not limited to—energy and environmental issues to be used as class discussion, as writing assignments, and/or for internet forums. Notes on discussion ideas and results are included in the instructor's manual.

## Debatable Issue

France currently gets more than 75% of its power from nuclear energy and now claims a substantial level of energy independence and almost the lowest-cost electricity in Europe. It also has an extremely low level of $CO_2$ emissions per capita from electricity generation. Why is nuclear power not used more extensively in other European countries or in the United States?

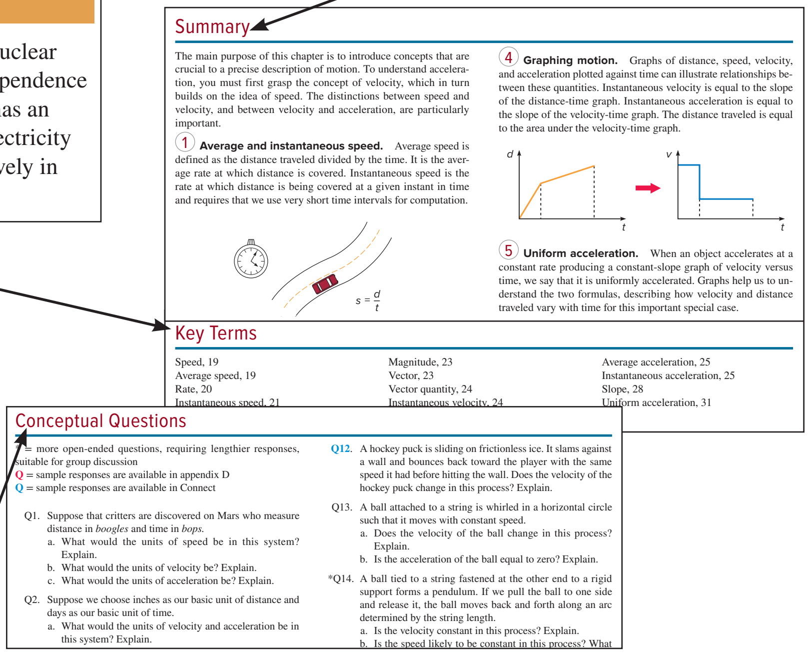
### End-of-Chapter Features

- The **summary** highlights the key elements of the chapter and correlates to the questions asked about the chapter's major concepts in the chapter opener.

Summary

Key Terms

Conceptual Questions


Summary

The main purpose of this chapter is to introduce concepts that are crucial to a precise description of motion. To understand acceleration, you must first grasp the concept of velocity, which in turn builds on the idea of speed. The distinctions between speed and velocity, and between velocity and acceleration, are particularly important.

1 **Average and instantaneous speed.** Average speed is defined as the distance traveled divided by the time. It is the average rate at which distance is covered. Instantaneous speed is the rate at which distance is being covered at a given instant in time and requires that we use very short time intervals for computation.

4 **Graphing motion.** Graphs of distance, speed, velocity, and acceleration plotted against time can illustrate relationships between these quantities. Instantaneous velocity is equal to the slope of the distance-time graph. Instantaneous acceleration is equal to the slope of the velocity-time graph. The distance traveled is equal to the area under the velocity-time graph.

5 **Uniform acceleration.** When an object accelerates at a constant rate producing a constant-slope graph of velocity versus time, we say that it is uniformly accelerated. Graphs help us to understand the two formulas, describing how velocity and distance traveled vary with time for this important special case.



Key Terms

Speed, 19
Average speed, 19
Rate, 20
Instantaneous speed, 21
Magnitude, 23
Vector, 23
Vector quantity, 24
Instantaneous velocity, 24
Average acceleration, 25
Instantaneous acceleration, 25
Slope, 28
Uniform acceleration, 31

Conceptual Questions

* = more open-ended questions, requiring lengthier responses, suitable for group discussion
Q = sample responses are available in appendix D
Q = sample responses are available in Connect

Q1. Suppose that critters are discovered on Mars who measure distance in *boogles* and time in *bops*.
a. What would the units of speed be in this system? Explain.
b. What would the units of velocity be? Explain.
c. What would the units of acceleration be? Explain.

Q2. Suppose we choose inches as our basic unit of distance and days as our basic unit of time.
a. What would the units of velocity and acceleration be in this system? Explain.

Q12. A hockey puck is sliding on frictionless ice. It slams against a wall and bounces back toward the player with the same speed it had before hitting the wall. Does the velocity of the hockey puck change in this process? Explain.

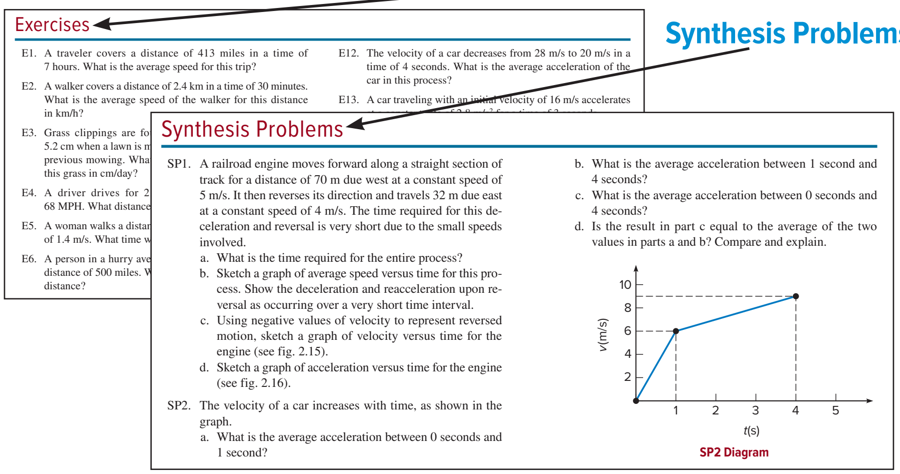
Q13. A ball attached to a string is whirled in a horizontal circle such that it moves with constant speed.
a. Does the velocity of the ball change in this process? Explain.
b. Is the acceleration of the ball equal to zero? Explain.

*Q14. A ball tied to a string fastened at the other end to a rigid support forms a pendulum. If we pull the ball to one side and release it, the ball moves back and forth along an arc determined by the string length.
a. Is the velocity constant in this process? Explain.
b. Is the speed likely to be constant in this process? What

- **Key terms** are page-referenced to where students can find the terms defined in context.
- **Conceptual Questions** are designed to challenge students to demonstrate their understanding of the key concepts. Selected answers are provided in appendix D to assist students with their study of more difficult concepts.

Exercises

Synthesis Problems


Exercises

E1. A traveler covers a distance of 413 miles in a time of 7 hours. What is the average speed for this trip?

E2. A walker covers a distance of 2.4 km in a time of 30 minutes. What is the average speed of the walker for this distance in km/h?

E3. Grass clippings are fo... 5.2 cm when a lawn is m... previous mowing. Wha... this grass in cm/day?

E4. A driver drives for 2... 68 MPH. What distance...

E5. A woman walks a distan... of 1.4 m/s. What time w...

E6. A person in a hurry ave... distance of 500 miles. W... distance?

E12. The velocity of a car decreases from 28 m/s to 20 m/s in a time of 4 seconds. What is the average acceleration of the car in this process?

E13. A car traveling with an initial velocity of 16 m/s accelerates

Synthesis Problems

SP1. A railroad engine moves forward along a straight section of track for a distance of 70 m due west at a constant speed of 5 m/s. It then reverses its direction and travels 32 m due east at a constant speed of 4 m/s. The time required for this deceleration and reversal is very short due to the small speeds involved.
a. What is the time required for the entire process?
b. Sketch a graph of average speed versus time for this process. Show the deceleration and reacceleration upon reversal as occurring over a very short time interval.
c. Using negative values of velocity to represent reversed motion, sketch a graph of velocity versus time for the engine (see fig. 2.15).
d. Sketch a graph of acceleration versus time for the engine (see fig. 2.16).

SP2. The velocity of a car increases with time, as shown in the graph.
a. What is the average acceleration between 0 seconds and 1 second?
b. What is the average acceleration between 1 second and 4 seconds?
c. What is the average acceleration between 0 seconds and 4 seconds?
d. Is the result in part c equal to the average of the two values in parts a and b? Compare and explain.

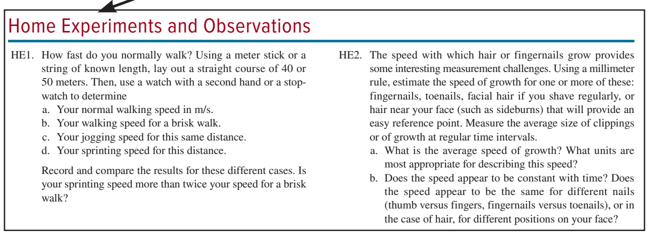


SP2 Diagram

- **Exercises** and **synthesis problems** are intended to help students test their grasp of problem solving. The odd-numbered exercises have answers in appendix D. By working through the odd-numbered exercises and checking the answers in appendix D, students can gain confidence in tackling the even-numbered exercises, and thus reinforce their problem-solving skills.

- Because many courses for non-science majors do not have a laboratory component, **home experiments and observations** are found at the end of each chapter. The spirit of these home experiments is to enable students to explore the behavior of physical phenomena using easily available rulers, string, paper clips, balls, toy cars, flashlight batteries, and so on. Many instructors have found them useful for putting students into the exploratory and observational frame of mind that is important to scientific thinking. This is certainly one of our objectives in developing scientific literacy.

Home Experiments and Observations


Home Experiments and Observations

HE1. How fast do you normally walk? Using a meter stick or a string of known length, lay out a straight course of 40 or 50 meters. Then, use a watch with a second hand or a stopwatch to determine
a. Your normal walking speed in m/s.
b. Your walking speed for a brisk walk.
c. Your jogging speed for this same distance.
d. Your sprinting speed for this distance.

Record and compare the results for these different cases. Is your sprinting speed more than twice your speed for a brisk walk?

HE2. The speed with which hair or fingernails grow provides some interesting measurement challenges. Using a millimeter rule, estimate the speed of growth for one or more of these: fingernails, toenails, facial hair if you shave regularly, or hair near your face (such as sideburns) that will provide an easy reference point. Measure the average size of clippings or of growth at regular time intervals.
a. What is the average speed of growth? What units are most appropriate for describing this speed?
b. Does the speed appear to be constant with time? Does the speed appear to be the same for different nails (thumb versus fingers, fingernails versus toenails), or in the case of hair, for different positions on your face?

> *"Students and faculty alike will find the home experiments engaging. Physics is not a spectator sport and participation is key."*
>
> —Juliet W. Brosing, Author

## Supplements

**Text Website**

In addition, a text-specific website provides instructor's access to useful study tools designed to help improve student understanding of the material presented in the text and class. For the instructor, the website is designed to help ease the time burdens of the course by providing valuable presentation and preparation tools.

PowerPoint Lectures
Instructor's Manual
Sample Syllabi
Clicker Questions
PowerPoints of Art and Photos from the Text
Test Bank
Formula Summaries
Animations

For sharing with students:

- Author-narrated videos illustrating physics in everyday situations (noted in text with a video icon) ▶
- Know
- Understand
- Study Hints

## Personal Response Systems

Personal Response Systems can bring interactivity into the classroom or lecture hall. Wireless response systems such as Poll Everywhere give the instructor and students immediate feedback from the entire class. Poll Everywhere allows students to use their computer, smartphone, tablet, or text message device to respond to questions. Instructors are able to motivate student preparation, interactivity, and active learning, receiving immediate feedback to gauge which concepts students understand. Questions covering the content of *The Physics of Everyday Phenomena* text are formatted in PowerPoint and are available on the text website for use with any personal response system.

## Computerized Test Bank Online

A comprehensive bank of test questions is provided on the text website within a computerized test bank powered by TestGen. TestGen allows you to create paper and online tests or quizzes in this easy-to-use program!

## Acknowledgments

A large number of people have contributed to this ninth edition, either directly or indirectly. We extend particular thanks to those who participated in reviews of the previous editions. Their thoughtful suggestions have had direct impact upon the clarity and accuracy of this edition, even when it was not possible to fully incorporate all of their ideas due to space limitations or other constraints. We also thank the contributors of the ninth edition supplements and digital products: Edward Ackad, Elizabeth Holden, and Jessie Martin.

We also wish to acknowledge the contributions of the editorial staff and book team members at McGraw-Hill Higher Education. Their commitment of time and enthusiasm for this work has helped enormously in pushing this project forward. We also owe a huge debt of thanks to our colleagues at Pacific University for helpful suggestions as well as for their forbearance when this project limited our time for other activities. Many other users have also provided constructive criticisms or suggestions, such as Jerry Clifford, Seton Hall University, Mikolaj Sawicki, John A. Logan College, and Mike Crivello, San Diego Mesa College.

Last, but certainly not least, we would both like to acknowledge the support of our families, friends, and colleagues. Their encouragement has been essential and has allowed us to enjoy the pleasure of this endeavor.

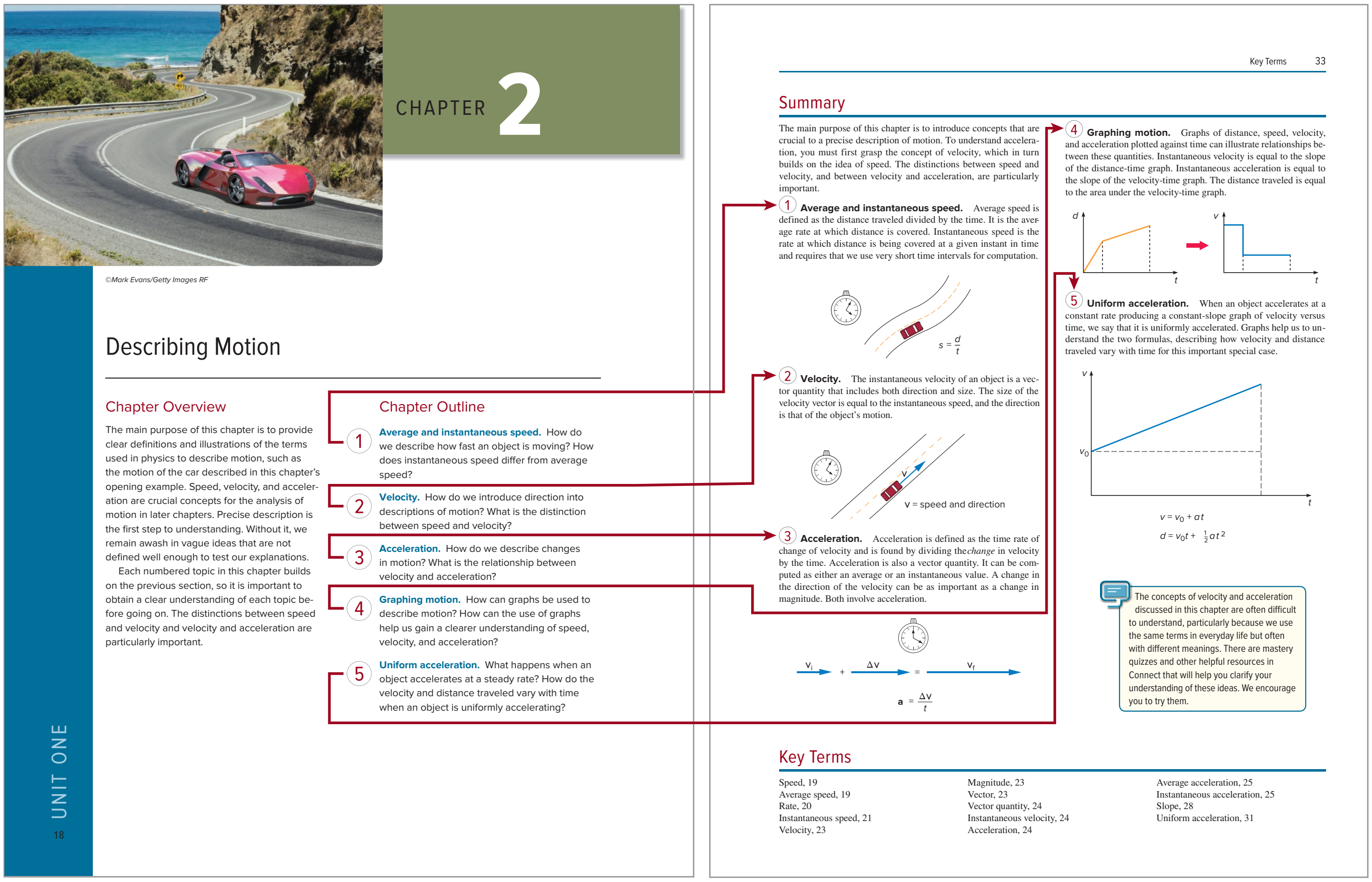
# Secrets to Success in Studying Physics

First of all, we should admit that there are no secrets. Conscientious work and follow-through with reading, problem assignments, and class participation will reap the rewards that students can expect from such efforts in other courses. Failing to do so will also lead to expected results.

There are some ways, however, in which studying physics is different from your studies in biology, history, or many other courses. Physics is not an area of study that can be mastered by memorizing discrete facts or by cramming before tests. Students sometimes bring study strategies to physics that have worked in other courses and are disappointed when they fail to work in their physics class. The suggestions that follow are sure-fire steps to getting the most out of your physics course and this textbook.

1. ***Experiment.*** Experiments play a key role in the development of physics but also in the growth of understanding for anyone approaching physics concepts. We often suggest in the text that you try simple experiments that might involve throwing a ball, walking across a room, or other very rudimentary activities. Do them right away as they arise in the text. Not only will you gain the benefit of increased blood flow to various parts of the body including the brain, but what follows in your reading will make more sense. Experience with everyday phenomena cannot be gained passively.
2. ***Get the big picture.*** Physics is a big-picture subject. Your understanding of Newton's laws of motion, for example, cannot be encapsulated by a formula or by memorizing the laws themselves. You need to see the entire context, understand the definitions, and work with how the laws are applied. The outlines and summaries provided at the beginning and end of each chapter can help to provide the context. They cannot stand alone, however. You need to place the examples and descriptions provided in the classroom and text in the framework provided by the outlines and summaries. If you grasp the big picture, the details will often follow.
3. ***Explore questions.*** The textbook provides a list of conceptual questions at the end of each chapter, but also raises questions in the body of the text. The greatest benefit is gained by attacking these questions first on your own and then by discussion with classmates. Write out answers to these questions using full sentences, not just short-answer phrases. Compare your answers with those provided at the back of the text for selected questions, but only after having a good crack at answering the questions yourself.
4. ***Try the exercises.*** The textbook also provides exercises and synthesis problems at the end of each chapter. Their purpose is to provide practice with simple numerical applications of physics concepts. They are useful only if you do them yourself and write out the solution steps in such a way that you can follow your work. Copying answers and steps from classmates or other sources may gain points on the assignment but provides no benefit in understanding. As in sports and many other activities, success on physics exams will come to those who practice.
5. ***Be there.*** College students set their own priorities for use of time, and sometimes class attendance is not at the top of the list. In some classes, this may be justified by the nature of the benefit of class activities, but that is seldom the case in physics. The demonstrations, explanations, working of exercises, and class discussions that are usually part of what occurs during a physics class provide an invaluable aid to grasping the big picture and filling in holes in your understanding. The demonstrations alone are often worth the price of admission. (You do pay—it's called tuition.)
6. ***Ask questions.*** If the explanations of demonstrations or other issues are not clear, ask questions. If you are confused, chances are good that many other students are likewise befuddled. They will love you for raising the flag. Unless the instructor is unusually insecure, he or she will also love you for providing the opportunity to achieve better clarity. Physics instructors already know this stuff, so they sometimes have difficulty seeing where student hang-ups may lie. Questions provide the lubrication for moving things forward.
7. ***Review understanding.*** Preparing for tests should not be a matter of last-minute cramming and memorization. Instead, you should review your understanding of the big picture and question yourself on why we did what we did in answering questions and working exercises done previously. Memorization is usually pointless because many physics instructors provide or permit formula sheets that may include definitions and other information. Late-night cramming is counterproductive because it detracts from getting a good night's sleep. Sleep can be critical to having a clear head the next day to meet the challenges provided by the test.

Although there is an element of common sense in most of these suggestions, you will probably not be surprised to learn that many students do not approach things following these guidelines. Old habits are hard to break and peer pressure can also be a negative influence at times. Students fall into patterns that they know are ineffective, but are unable to climb out of the rut. We have done our duty in disclosing these secrets. You are on your own if you choose a different path. Let us know if it works.



CHAPTER 2

©Mark Evans/Getty Images RF

Describing Motion

Chapter Overview

The main purpose of this chapter is to provide clear definitions and illustrations of the terms used in physics to describe motion, such as the motion of the car described in this chapter's opening example. Speed, velocity, and acceleration are crucial concepts for the analysis of motion in later chapters. Precise description is the first step to understanding. Without it, we remain awash in vague ideas that are not defined well enough to test our explanations.

Each numbered topic in this chapter builds on the previous section, so it is important to obtain a clear understanding of each topic before going on. The distinctions between speed and velocity and velocity and acceleration are particularly important.

Chapter Outline

1 **Average and instantaneous speed.** How do we describe how fast an object is moving? How does instantaneous speed differ from average speed?

2 **Velocity.** How do we introduce direction into descriptions of motion? What is the distinction between speed and velocity?

3 **Acceleration.** How do we describe changes in motion? What is the relationship between velocity and acceleration?

4 **Graphing motion.** How can graphs be used to describe motion? How can the use of graphs help us gain a clearer understanding of speed, velocity, and acceleration?

5 **Uniform acceleration.** What happens when an object accelerates at a steady rate? How do the velocity and distance traveled vary with time when an object is uniformly accelerating?

UNIT ONE

18

Key Terms 33

Summary

The main purpose of this chapter is to introduce concepts that are crucial to a precise description of motion. To understand acceleration, you must first grasp the concept of velocity, which in turn builds on the idea of speed. The distinctions between speed and velocity, and between velocity and acceleration, are particularly important.

1 **Average and instantaneous speed.** Average speed is defined as the distance traveled divided by the time. It is the average rate at which distance is covered. Instantaneous speed is the rate at which distance is being covered at a given instant in time and requires that we use very short time intervals for computation.

$s = \frac{d}{t}$

2 **Velocity.** The instantaneous velocity of an object is a vector quantity that includes both direction and size. The size of the velocity vector is equal to the instantaneous speed, and the direction is that of the object's motion.

v = speed and direction

3 **Acceleration.** Acceleration is defined as the time rate of change of velocity and is found by dividing the *change* in velocity by the time. Acceleration is also a vector quantity. It can be computed as either an average or an instantaneous value. A change in the direction of the velocity can be as important as a change in magnitude. Both involve acceleration.

$v_i + \Delta v = v_f$

$\mathbf{a} = \frac{\Delta v}{t}$

4 **Graphing motion.** Graphs of distance, speed, velocity, and acceleration plotted against time can illustrate relationships between these quantities. Instantaneous velocity is equal to the slope of the distance-time graph. Instantaneous acceleration is equal to the slope of the velocity-time graph. The distance traveled is equal to the area under the velocity-time graph.

5 **Uniform acceleration.** When an object accelerates at a constant rate producing a constant-slope graph of velocity versus time, we say that it is uniformly accelerated. Graphs help us to understand the two formulas, describing how velocity and distance traveled vary with time for this important special case.

$v = v_0 + at$

$d = v_0t + \frac{1}{2}at^2$

The concepts of velocity and acceleration discussed in this chapter are often difficult to understand, particularly because we use the same terms in everyday life but often with different meanings. There are mastery quizzes and other helpful resources in Connect that will help you clarify your understanding of these ideas. We encourage you to try them.

Key Terms

| | | |
|---|---|---|
| Speed, 19 | Magnitude, 23 | Average acceleration, 25 |
| Average speed, 19 | Vector, 23 | Instantaneous acceleration, 25 |
| Rate, 20 | Vector quantity, 24 | Slope, 28 |
| Instantaneous speed, 21 | Instantaneous velocity, 24 | Uniform acceleration, 31 |
| Velocity, 23 | Acceleration, 24 | |

The chapter outline and chapter summary provide related frameworks for organizing concepts.

# study hint:

## How to Use the Features of This Book

This book has a number of features designed to make it easier for you to organize and grasp the concepts that we will explore. These features include the chapter overview and outline at the beginning of each chapter and the summary at the end of each chapter, as well as the structure of individual sections of the chapters. The questions, exercises, and synthesis problems at the end of each chapter also play an important role. How can these features be used to the best advantage?

## Chapter outlines and summaries

Knowing where you are heading before you set out on a journey can be the key to the success of your mission. Students get a better grasp of concepts if they have some structure or framework to help them to organize the ideas. Both the chapter overview and outline at the beginning of each chapter and the summary at the end are designed to provide such a framework. Having a clear idea of what you are trying to accomplish before you invest time in reading a chapter will make your reading more effective and enjoyable.

The list of topics and questions in the chapter outline can be used as a checklist for measuring your progress as you read. Each numbered topic in the outline, with its associated questions, pertains to a section of the chapter. The outline is designed to stimulate your curiosity by providing some blanks (unanswered questions) to be filled in by your reading. Without the blanks, your mind has no organizational structure to store the information. Without structure, recall is more difficult. You can use the questions in the outline to check the effectiveness of your reading. Can you answer all of the questions when you are done? Each section of a chapter also begins with questions, and the section subheadings are likewise often cast as questions. At the end of each section there is also an indented summary paragraph designed to help you tie the ideas in that section together.

The end-of-chapter summary gives a short description of the key ideas in each section, often cast in the form of answers to the questions raised in the outline (see diagram). Summaries provide a quick review, but they are no substitute for a careful reading of the main text. By following the same organizational structure as the outline, the summary reminds you where to find a more complete discussion of these ideas. The purpose of both the outlines and the summaries is to make your reading more organized and effective.

Studying any new discipline requires forming new patterns of thought that can take time to gel. The summaries at the end of each section, as well as at the end of the chapter, can help this gelling to take place. A structure is often built layer by layer, and the later layers will be shaky if the base is unstable.

## How should the questions and exercises be used?

At the end of each chapter you will find a group of questions, followed by a group of exercises, and, finally, by a small number of synthesis problems. Your grasp of the chapter will improve if you write out answers to the questions and exercises, either as assigned by your instructor or in independent study. The ideas contained in each chapter cannot be thoroughly mastered without this kind of practice.

The questions are crucial to helping you fix the important concepts and distinctions in your mind. Most of the questions call for a short answer as well as an explanation. A few of the questions, marked with asterisks, are more open-ended and call for lengthier responses. It is a good idea to write out the explanations in clear sentences when you answer these questions, because it is only through reinforcement that ideas become a part of you. Also, if you can explain something clearly to someone else, you understand it. A sample question and answer appears in example box 1.1.

The exercises are designed to give you practice in using the ideas and the related formulas to do simple computations. The exercises also help to solidify your understanding of concepts by giving you a sense of the units and the sizes of the quantities involved. Even though many of the exercises are straightforward enough to work in your head without writing much down, we recommend writing out the information given, the information sought, and the solution in the manner shown in example boxes 1.2 and 1.3 in section 1.3. This develops careful work habits that will help you avoid careless mistakes. Most students find the exercises easier than the questions. The sample exercises scattered through each chapter can help you get started.

The synthesis problems are more wide-ranging than the questions or exercises. They often involve features of both. Although not necessarily harder than the questions or exercises, they do take more time and are sometimes used to extend ideas beyond what was discussed in the chapter. Doing one or two of these in each chapter should build your confidence. They are particularly recommended for those students who have worked the exercises and want to explore the topic in more depth.

Answers to the odd-numbered exercises, odd-numbered synthesis problems, and selected questions are found in the back of the book in appendix D. Looking up the answer before attempting the problem is self-defeating. It deprives you of practice in thinking things through on your own. Checking answers *after* you have worked an exercise can be a confidence builder. Answers should be used only to confirm or improve your own thinking.

## Home experiments and everyday phenomenon boxes

Reading or talking about physical ideas is useful, but there is no substitute for hands-on experience with the phenomena. You already have a wealth of experience with many of these phenomena, but you probably have not related it to the physical concepts you will be learning. Seeing things in new ways will make you a more astute observer.

In addition to the home experiments at the end of each chapter, we often suggest some simple experiments in the main text or in the study hints. We strongly recommend making these observations and doing the experiments. Lecture demonstrations can help, but doing something yourself imprints it vividly on your mind. There is excitement in discovering things yourself and seeing them in a new light.

The boxes that discuss everyday phenomena also give you practice in applying physical concepts. Most of the phenomena discussed in these boxes are familiar. The boxes allow us to explore these examples more thoroughly. Participating in these investigations of everyday phenomena can help bring the ideas home.

Connect has many features that will help you be successful in the course. The study hints given for each chapter often give a concise and thorough summary of the chapter. Read them to check if you have understood the key points of each chapter. There are both mastery quizzes and practice problems provided. Mastery quizzes test your conceptual understanding of the material. Many of the your exam questions may be worded similar to these quizzes. Practice problems allow you to practice problems similar to the exercises at the end of each chapter in the text. Complete solutions are provided for these and you can check them after trying the problems.

Ninth Edition

# The Physics
## of Everyday Phenomena

A Conceptual Introduction to Physics

CHAPTER 1

Source: NASA/Langley Research Center (NASA-LaRC)

# Physics, the Fundamental Science

## Chapter Overview

The main objective of this chapter is to help you understand what physics is and where it fits in the broader scheme of the sciences. A secondary purpose is to acquaint you with the metric system of units and the advantages of the use of simple mathematics.

## Chapter Outline

1. **What about energy?** What is the current debate regarding global warming all about? What do concerns about global warming and climate change have to do with energy? How is physics involved in these discussions?

2. **The scientific enterprise.** What is the scientific method? How do scientific explanations differ from other types of explanation?

3. **The scope of physics.** What is physics? How is it related to the other sciences and to technology? What are the major subfields of physics?

4. **The role of measurement and mathematics in physics.** Why are measurements so important? Why is mathematics so extensively used in science? What are the advantages of the metric system of units?

5. **Physics and everyday phenomena.** How is physics related to everyday experience and common sense? What are the advantages of using physics to understand common experience?

Imagine that you are riding your bike on a country road on an Indian-summer afternoon. The sun has come out after a brief shower, and as the rain clouds move on, a rainbows appears in the east (fig. 1.1). A leaf flutters to the ground, and an acorn, shaken loose by a squirrel, misses your head by only a few inches. The sun is warm on your back, and you are at peace with the world around you.

No knowledge of physics is needed to savor the moment, but your curiosity may bring some questions to mind. Why does the rainbow appear in the east rather than in the west, where it may also be raining? What causes the colors to appear? Why does the acorn fall more rapidly than the leaf? Why is it easier to keep your bicycle upright while you are moving than when you are standing still?

Your curiosity about questions like these is similar to what motivates scientists. Learning to devise and apply theories or models that can be used to understand, explain, and predict such phenomena can be a rewarding intellectual game. Crafting an explanation and testing it with simple experiments or observations is fun. That enjoyment is often missed when the focus of a science course is on accumulating facts.

This book can enhance your ability to enjoy the phenomena that are part of everyday experience. Learning to produce your own explanations and to perform simple experimental tests can be gratifying. The questions posed here lie in the realm of physics, but the spirit of inquiry and explanation is found throughout science and in many other areas of human activity. The greatest rewards of scientific study are the fun and excitement that come from understanding something that has not been understood before. This is true whether we are talking about a physicist making a major scientific breakthrough or about a bike rider understanding how rainbows are formed. There are also real benefits to understanding the physics concepts that underlie issues arising in political and policy debates. The next section introduces questions in the very important areas of energy use and climate change. These involve everyday phenomena of a more pressing nature than rainbows.

**Figure 1.1** Rainbows appear to the east in late afternoon. How can this phenomenon be explained? (See everyday phenomenon box 17.1.) *Courtesy of Sally Cantrell Griffith*

## Study Hint

If you have a clear idea of what you want to accomplish before you begin to read a chapter, your reading will be more effective. The questions in the chapter outline—as well as those in the subheadings of each section—can serve as a checklist for measuring your progress as you read. A clear picture of what questions are going to be addressed and where the answers will be found forms a mental road map to guide you through the chapter. Take a few minutes to study the outline and fix this road map in your mind. It will be time well spent.

## 1.1 What about Energy?

Suppose that you have just emerged from a heated argument with a friend about global warming and energy. Your friend has a different political bent than your own and you suspect that his or her opinions on global warming are simply a matter of political bias. However, since you may know very little about the details of energy issues, you are really not in a position to counter the arguments. Where do you go from there?

All of us find ourselves in this position from time to time. Energy issues lie at the heart of the political debate on global warming and climate change. Understanding the basics of these issues is important to politicians, policymakers, and ordinary citizens who discuss these issues and vote for or against ballot measures and candidates. What is energy and how is it used? Which energy sources are renewable and which are not? What does it mean to be "green" these days, and what can you do as an individual to counter global warming (should you believe that it is occurring)?

## The global warming debate

What are the disagreements about **global warming?** Actually, there is little argument among climate scientists that the Earth is warming up and has been for several hundred years or more. People who argue otherwise are ignoring a large body of data regarding the average temperature of the Earth. This warming may seem very slow, just one or two degrees Fahrenheit in a century or more, but the rate of increase has been growing over the last 50 years, as shown in figure 1.2. It is this increasing rate of warming that has alarmed many climate scientists.

There are numerous fluctuations in global temperatures and there are cyclic effects whose causes are only partly understood, but these cannot mask the longer-term trend of gradual warming. The increased rate of warming observed during the 1990s may have been partly the result of one of the cyclic effects just as the recent decrease in the rate of warming may also reflect the downside of one of these cycles. Beware of arguments that focus on these short-term effects. It is the long-term effects that are most relevant.

Within the scientific community, the debate is not about whether global warming is occurring, but rather about what is causing the warming and how it will progress. The role played by human-caused changes in the environment is one of the basic questions. Specifically, we know that the burning of **fossil fuels** (coal, oil, and natural gas) increases the amount of carbon dioxide in the atmosphere. Carbon dioxide is one of the so-called "**greenhouse gases**" that slow the escape of heat from the Earth's surface and therefore should contribute to the warming of the Earth. (See chapter 10 for a discussion of the greenhouse effect.) Our use of fossil fuels is thus an important part of the debate.

The factors that affect the Earth's climate are complex and difficult to model. Scientists have made considerable progress in developing computer models that are capable of capturing many aspects of climate change. These models have had good success in describing what has happened over the last 50 or so years of climate variations, but their accuracy for predicting future climate change is still in question. We expect that increases in greenhouse gases should produce more warming, but unknown factors such as possible changes in global cloud cover make accurate predictions difficult.

## How is energy involved?

What does all of this have to do with energy? As we have already indicated, much of our use of energy involves the burning of fossil fuels. The carbon that is released in this process was locked up millions of years ago in coal, oil, and natural gas. Therefore, this carbon has not been a part of ongoing processes that absorb and release carbon dioxide. From the perspective of geological time frames, this burning of fossil fuels is happening on a very short time scale. It is a geological flash in the pan. (See fig. 1.3.)

What are the natural ongoing processes involving carbon? Trees and other green plants absorb carbon dioxide from the atmosphere—it is essential to their growth. When the plants die, they decay, releasing some carbon dioxide back to the atmosphere. Forest or brush fires release carbon dioxide to the atmosphere more quickly. A small portion of the carbon in plants may get buried and may ultimately, over a period of many millions of years, be converted to a fossil fuel. When we burn wood as a fuel, we release carbon dioxide, but this has no long-term effect on greenhouse gases because the carbon dioxide released was absorbed from the atmosphere not too long ago. Wood burning does emit particles of ash and other pollutants that can have undesirable effects.

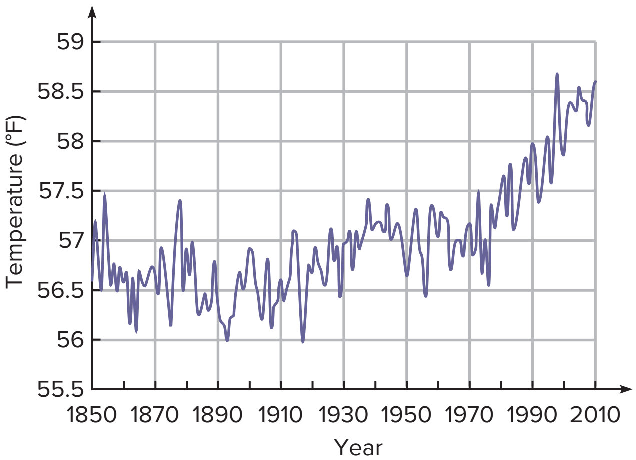



**Figure 1.2** Average surface temperature of the Earth since 1850. (Graph produced from data reported by Intergovernmental Panel on Climate Change.) The rise over the past 50 years corresponds roughly with an increase in atmospheric carbon dioxide.

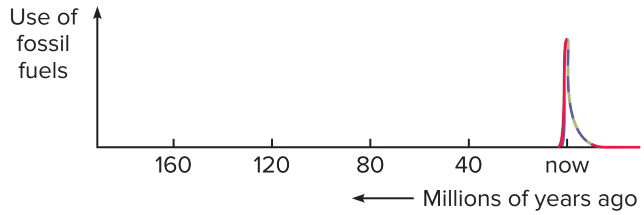



**Figure 1.3** A schematic sketch of our use of fossil fuels on a geologic time scale. Coal, oil, and natural gas were produced anywhere from 40 to 200 million years ago.

The reduction of forest cover to create cities, highways, and the like therefore also affects the balance of carbon dioxide in the atmosphere. But it is the burning of fossil fuels that has the greatest impact, and that is where the focus must be if we are to change the rate at which greenhouse gases are increasing. This, then, gets us into the familiar debates on how we produce energy, how we use energy, and what can be done to change these patterns.

But what is energy? Although the term is bandied about all the time and we all think we have some sense of what it means, it turns out that providing a satisfactory definition is not a trivial matter. Many of the misunderstandings involved in the global-warming debate result from poor understanding of what energy is. For example, is hydrogen a source of energy or merely a means of transporting energy, and what is the difference (see everyday phenomenon box 18.1)? Much of the political hoopla regarding the hydrogen economy failed to address this basic question.

In this book, we will define energy initially in chapter 6, titled "Energy and Oscillations." The prior chapters on mechanics provide the underpinnings for the introduction of the energy concept. In fact, it is difficult to understand how energy is defined without having some knowledge of mechanics. Following the introduction in chapter 6, energy ideas appear and are expanded in all of the chapters that follow. These ideas are central to all of physics.

## Physics and energy

Understanding the definition of energy is obviously a good starting point for discussions of energy policies. The meaning of energy and the nature of energy transformations are firmly within the realm of physics. How we convert one form of energy to another, how we can use energy efficiently, and what it means to conserve energy are all topics that will come up in this book and in the study of physics more generally.

Many other topics within the realm of physics also play important roles in addressing energy issues. For example, transportation is a major area of energy use in our society. Cars, trucks, airplanes, boats, and trains are all part of the mix. They all utilize energy in some manner, but their basic physics can be understood from ideas in mechanics that are discussed in the early chapters of this book before energy ideas are introduced.

In the short term, one of our best options for reducing our use of fossil fuels involves energy conservation. Changes can be made in this realm more quickly than in the development of alternative energy resources. The rising costs of gasoline, diesel fuel, and fuel oil for heating have already been shown to significantly affect our energy consumption. Strictly speaking, we do not really consume energy—we simply convert it to less usable forms (see chapter 6 and chapter 11). The study of the mechanics of transportation (chapters 2–4) and the thermodynamics of engines (chapters 9–11) play important roles in energy conservation.

**Figure 1.4** Are nuclear power plants our salvation or relics of the past? *©Aerial Archives/Alamy Stock Photo*

Questions regarding choices on how to generate usable forms of energy all involve physics concepts. Is it better to use natural gas than nuclear power (fig. 1.4), for example? Nuclear power has been a particularly contentious issue for many years and has suffered somewhat from the whims of political fashion. What is nuclear energy, and should we be rushing into a new commitment to its use, or should we be afraid of going there? Natural gas releases less carbon dioxide per unit of energy generated than do coal or oil, and it is a relatively clean fuel. It is, however, an emitter of greenhouse gases, and its long-term supply is questionable.

Nuclear power does not involve the burning of a carbon-based fuel, so it does not release carbon dioxide into the atmosphere. For this reason, it is now receiving renewed attention as a possible resource for reducing our "carbon footprint." Nuclear power does involve the mining of a limited resource, uranium, and has serious environmental issues associated with mining, possible accidents, and waste disposal. However, the utilization of any energy resource has environmental consequences, so the weighing of such issues must be an important aspect of our decision making.

We will not provide a definitive answer to the questions we have just raised. What we will do is discuss some of the basic physics underlying nuclear power, natural-gas power plants, and other resources used in electric power generation. Fossil-fuel power plants are discussed in chapter 11 and nuclear power is addressed in chapter 19. Many other means of generating energy will also be discussed, and some of the pros and cons of their use will be indicated in many different sections of the book.

After studying these issues, will you win your argument with your friend? Perhaps not, but you will be in a much better position to debate the questions. Both of you may come to a better understanding of the real issues involved.

> Political debates on climate change and energy utilization are important features of current events. The two topics are intimately related because the burning of fossil fuels for energy generation is the primary cause of release into the atmosphere of the greenhouse gas, carbon dioxide. Physics is the science of energy and is therefore heavily involved in decisions on energy conversion and utilization. Thus, the study of physics provides a basis for understanding some of the fundamental issues in these debates.

## 1.2 The Scientific Enterprise

How do scientists go about explaining something like the temperature change of the Earth or the rainbow described in the introduction? How do scientific explanations differ from other types of explanations? Can we count on the scientific method to explain almost anything? It is important to understand what science can and cannot do.

Philosophers have devoted countless hours and pages to questions about the nature of knowledge, and of scientific knowledge in particular. Many issues are still being refined and debated. Science grew rapidly during the twentieth century and has had a tremendous impact on our lives. Innovations in medicine, communications, transportation, and computer technology all have resulted from advances in science. What is it about science that explains its impressive advances and steady expansion?

### Science and rainbows

Let's consider a specific example of how a scientific explanation comes to be. Where would you turn for an explanation of how rainbows are formed? If you returned from your bike ride with that question on your mind, you might look up "rainbow" in a textbook on physics or on the Internet, and read the explanation found there. Are you behaving like a scientist?

The answer is both yes and no. Many scientists would do the same if they were unfamiliar with the explanation. When we do this, we appeal to the authority of the textbook author and to those who preceded the author in inventing the explanation. Appeal to authority is one way of gaining knowledge, but you are at the mercy of your source for the validity of your explanation. You are also hoping that someone has already raised the same question and done the work to create and test an explanation.

Suppose you go back three hundred years or more and try the same approach. One book might tell you that a rainbow is a painting of the angels. Another might speculate on the nature of light and its interactions with raindrops but be quite tentative in its conclusions. Either of these books might have seemed authoritative in its day. Where, then, do you turn? Which explanation will you accept?

If you are behaving like a scientist, you might begin by reading the ideas of other scientists about light and then test these ideas against your own observations of rainbows. You would carefully note the conditions when rainbows appear, the position of the sun relative to you and the rainbow, and the position of the rain shower. What is the order of the colors in the rainbow? Have you observed that order in other phenomena?

You would then invent an explanation or **hypothesis** using current ideas on light and your own guess about what happens as light passes through a raindrop. You could devise experiments with water drops or glass beads to test your hypothesis. (See chapter 17 for a modern view of how rainbows are formed.)

If your explanation is consistent with your observations and experiments, you could report it by giving a paper or talk to scientific colleagues. They may critique your explanation, suggest modifications, and perform their own experiments to confirm or refute your claims. If others confirm your results, your explanation will gain support and eventually become part of a broader **theory*** about phenomena involving light. The experiments you and others do may also lead to the discovery of new phenomena, which will call for refined explanations and theories.

What is critical to the process just described? First is the importance of careful observation. Another aspect is the idea of testability. An acceptable scientific explanation should suggest some means to test its predictions by observations or experiment. Saying that rainbows are the paintings of angels may be poetic, but it certainly is not testable by mere humans. It is not a scientific explanation.

Another important part of the process is a social one, the communication of your theory and experiments to colleagues (fig. 1.5). Submitting your ideas to the criticism (at times blunt) of your peers is crucial to the advancement of science. Communication is also important in assuring your own care in performing the experiments and interpreting the results. A scathing attack by someone who has found an important error or omission in your work is a strong incentive for being more careful in the future. One person working alone cannot hope to think of all of the possible ramifications, alternative explanations, or potential mistakes in an argument or theory. The explosive growth of science has depended heavily on cooperation and communication.

*The concept of a theory, as used in science, is often misunderstood. It is much more than a simple hypothesis. A theory consists of a set of basic principles from which many predictions can be deduced. The basic principles involved in the theory are often widely accepted by scientists working in the field.

**Figure 1.5** French physicist and chemist Marie Curie (1867–1937) gives a lecture to an audience of men and women at the Conservatory of Arts and Crafts, Paris, 1925. Curie won Nobel prizes for both Physics (1903) and Chemistry (1911). *©Jacques Boyer/Roger Viollet/Getty Images*

### What is the scientific method?

Is there something we could call the **scientific method** within this description, and if so, what is it? The process just described is a sketch of how the scientific method works. Although there are variations on the theme, this method is often described as shown in table 1.1.

The steps in table 1.1 are all involved in our description of how to develop an explanation of rainbows. Careful observation may lead to **empirical laws** for when and where rainbows appear. An empirical law is a generalization derived from experiments or observations. An example of an empirical law is the statement that we see rainbows with the sun at our backs as we look at the rainbow. This is an important clue for developing our hypothesis, which must be consistent with this rule. The hypothesis, in turn, suggests ways of producing rainbows artificially that could lead to experimental tests and, eventually, to a broader theory.

This description of the scientific method is not bad, although it ignores the critical process of communication. Few scientists are engaged in the full cycle that these steps suggest. Theoretical physicists, for example, may spend all of their time with step 3. Although they have some interest in experimental results, they may never do any experimental work themselves. Today, little science is done by simple observation as step 1 may seem to imply. Most observations are designed to test a hypothesis or existing theory and often involve carefully controlled experiments. Although the scientific method is presented here as a stepwise process, in reality these steps often happen simultaneously with much cycling back and forth between steps (fig. 1.6).

**Table 1.1**

Steps in the Scientific Method

1. Careful observation of natural phenomena.
2. Formulation of rules or empirical laws based on generalizations from these observations and experiments.
3. Development of hypotheses to explain the observations and empirical laws, and the refinement of hypotheses into theories.
4. Testing of the hypotheses or theories by further experiment or observation.

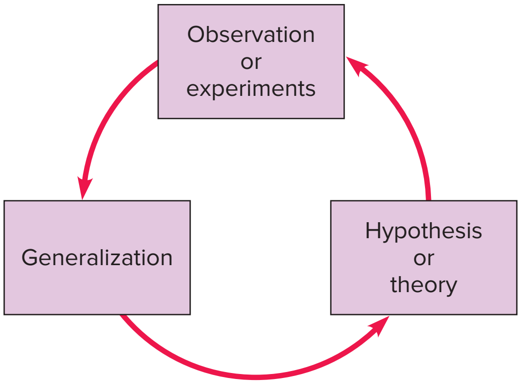



**Figure 1.6** The scientific method cycles back to observations or experiments as we seek to test our hypotheses or theories. Communication with peers is involved in all stages of the process.

The scientific method is a way of testing and refining ideas. Note that the method applies only when experimental tests or other consistent observations of phenomena are feasible. Testing is crucial for weeding out unproductive hypotheses; without tests, rival theories may compete endlessly for acceptance. Example box 1.1 provides a sample question and response illustrating these ideas.

### How should science be presented?

Traditional science courses focus on presenting the results of the scientific process rather than the story of how scientists arrived at these results. This is why the general public often

## Example Box 1.1

**Sample Question: How Reliable Is Astrology?**

**Question:** Astrologers claim that many events in our lives are determined by the positions of the planets relative to the stars. Is this a testable hypothesis?

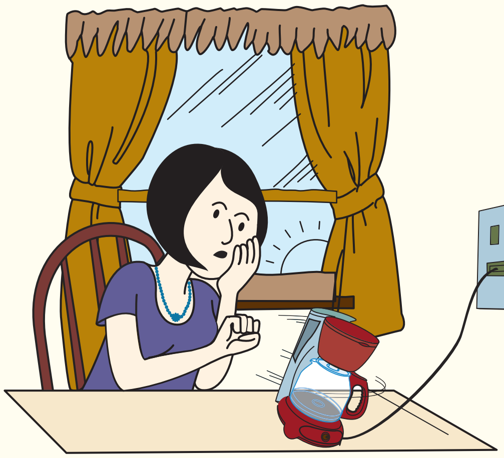
**Answer:** Yes, it could be tested if astrologers were willing to make explicit predictions about future events that could be verified by independent observers. In fact, astrologers usually carefully avoid doing this, preferring to cast their predictions as vague statements subject to broad interpretation. This prevents clean tests. Astrology is not a science!

## Everyday Phenomenon Box 1.1

### The Case of the Malfunctioning Coffee Pot

**The Situation.** It is Monday morning, and you are, as usual, only half-awake and feeling at odds with the world. You are looking forward to reviving yourself with a freshly brewed cup of coffee when you discover that your coffeemaker refuses to function. Which of these alternatives is most likely to work?

1. Pound on the appliance with the heel of your hand.
2. Search desperately for the instruction manual that you probably threw away two years ago.
3. Call a friend who knows about these things.
4. Apply the scientific method to troubleshoot the problem.



Fixing a malfunctioning coffee pot—alternative 1.

**The Analysis.** All of these alternatives have some chance of success. The sometimes positive response of electrical or mechanical appliances to physical abuse is well documented. The second two alternatives are both forms of appeal to authority that could produce results. The fourth alternative, however, may be the most productive and quickest, barring success with alternative 1.

How would we apply the scientific method as outlined in table 1.1 to this problem? Step 1 involves calmly observing the symptoms of the malfunction. Suppose that the coffeemaker simply refuses to heat up. When the switch is turned on, no sounds of warming water are heard. You notice that no matter how many times you turn the switch on or off, no heat results. This is the kind of simple generalization called for in step 2.

We can now generate some hypotheses about the cause of the malfunction, as suggested in step 3. Here are some candidates:

a. The coffee pot is not plugged in.
b. The external circuit breaker or fuse has tripped.
c. The power is off in the entire house or neighborhood.
d. An internal fuse in the coffee pot has blown.
e. A wire has come loose or burned through inside the coffeemaker.
f. The internal thermostat of the coffeemaker is broken.

No detailed knowledge of electrical circuits is needed to check these possibilities, although the last three call for more sophistication (and are more trouble to check) than the first three. The first three possibilities are the easiest to check and should be tested first (step 4 in our method). A simple remedy such as plugging in the pot or flipping on a circuit breaker may put you back in business. If the power is off in the building, other appliances (lights, clocks, and so on) will not work either, which provides an easy test. There may be little that you can do in this case, but at least you have identified the problem. Abusing the coffee pot will not help.

The pot may or may not have an internal fuse. If it is blown, a trip to the hardware store may be necessary. A problem like a loose wire or a burnt-out connection often becomes obvious by looking inside after you remove the bottom of the pot or the panel where the power cord comes in. (You must unplug the pot before making such an inspection!) If one of these alternatives is the case, you have identified the problem, but the repair is likely to take more time or expertise. The same is true of the last alternative.

Regardless of what you find, this systematic (and calm) approach to the problem is likely to be more productive and satisfying than the other approaches. Troubleshooting, if done this way, is an example of applying the scientific method on a small scale to an ordinary problem. We are all scientists if we approach problems in this manner.

sees science as a collection of facts and established theories. To some extent, that charge could be made against this book, because it describes theories that have resulted from the work of others without giving the full picture of their development. Building on the work of others, without needing to repeat their mistakes and unproductive approaches, is a necessary condition for human and scientific progress.

This book attempts to engage you in the process of making your own observations and developing and testing your own explanations of everyday phenomena. By doing home experiments or observations, constructing explanations of the results, and debating your interpretations with your friends, you will appreciate the give-and-take that is the essence of science.

Whether or not we are aware of it, we all use the scientific method in our everyday activities. The case of the malfunctioning coffee pot described in everyday phenomenon box 1.1 provides an example of scientific reasoning applied to ordinary troubleshooting.

The process of science begins with, and returns to, observations of or experiments on natural phenomena. Observations may suggest empirical laws, and these generalizations may be incorporated into a more comprehensive hypothesis. The hypothesis is then tested against more observations or by controlled experiments to form a theory. Working scientists are engaged in one or more of these activities, and we all use the scientific method on everyday problems.

### Debatable Issue

We are often told that there is a strong consensus among climate scientists that global warming and climate change are being caused by human activity that is producing growing amounts of greenhouse gases, particularly carbon dioxide, in the atmosphere. Does a strong consensus among scientists imply that this idea is correct? Why or why not?

## 1.3 The Scope of Physics

Where does physics fit within the sciences? Since this book is about physics, rather than biology, chemistry, geology, or some other science, it is reasonable to ask where we draw the lines between the disciplines. It is not possible, however, to make sharp distinctions among the disciplines or to provide a definition of physics that will satisfy everyone. The easiest way to give a sense of what physics is and does is by example—that is, by listing some of its subfields and exploring their content. First, let's consider a definition, however incomplete.

### How is physics defined?

Physics can be defined as the *study of the basic nature of matter and the interactions that govern its behavior.* It is the most fundamental of the sciences. The principles and theories of physics can be used to explain the fundamental interactions involved in chemistry, biology, and other sciences at the atomic or molecular level. Modern chemistry, for example, uses the physical theory of *quantum mechanics* to explain how atoms combine to form molecules. Quantum mechanics was developed primarily by physicists in the early part of this century, but chemists and chemical knowledge also played important roles. Ideas about energy that arose initially in physics are now used extensively in chemistry, biology, and other sciences.

The general realm of science is often divided into the life sciences and the physical sciences. The life sciences include the various subfields of biology and the health-related disciplines that deal with living organisms. The physical sciences deal with the behavior of matter in both living and nonliving systems. In addition to physics, the physical sciences include chemistry, geology, astronomy, oceanography, and meteorology (the study of weather). Physics underlies all of them.

Physics is also generally regarded as the most quantitative of the sciences. It makes heavy use of mathematics and numerical measurements to develop and test its theories. This aspect of physics has often made it seem less accessible to students, even though the models and ideas of physics can be described more simply and cleanly than those of other sciences. As we will discuss in section 1.4, mathematics serves as a compact language, allowing briefer and more precise statements than would be possible without its use. However, the quantitative skills needed to understand this book are minimal.

### What are the major subfields of physics?

The primary subfields of physics are listed and identified in table 1.2. Mechanics, which deals with the motion (or lack of motion) of objects under the influence of forces, was the first subfield to be explained with a comprehensive theory. Newton's theory of mechanics, which he developed in the last half of the seventeenth century, was the first full-fledged physical theory that made extensive use of mathematics. It became a prototype for subsequent theories in physics.

The first four subfields listed in table 1.2 were well developed by the beginning of the twentieth century, although all have continued to advance since then. These subfields—mechanics, thermodynamics, electricity and magnetism, and optics—are sometimes grouped as **classical physics.** The last four subfields—atomic physics, nuclear physics, particle physics, and condensed-matter physics—are often grouped under the heading of **modern physics,** even though all of the subfields are part of the modern practice of physics. The distinction is made because the last four subfields all emerged during

**Table 1.2**

The Major Subfields of Physics

**Mechanics.** The study of forces and motion.

**Thermodynamics.** The study of temperature, heat, and energy.

**Electricity and Magnetism.** The study of electric and magnetic forces and electric current.

**Optics.** The study of light.

**Atomic Physics.** The study of the structure and behavior of atoms.

**Nuclear Physics.** The study of the nucleus of the atom.

**Particle Physics.** The study of subatomic particles (quarks, etc.).

**Condensed-Matter Physics.** The study of the properties of matter in the solid and liquid states.

the twentieth century and only existed in rudimentary forms before the turn of that century. In addition to the subfields listed in table 1.2, many physicists work in interdisciplinary fields such as biophysics, geophysics, or astrophysics.

The photographs in this section (fig 1.7, fig. 1.8, fig. 1.9, and fig. 1.10) illustrate characteristic activities or applications of the subfields. The invention of the laser has been an extremely important factor in the rapid advances now taking place in optics, as well as many advances in the medical field (fig. 1.7). The development of the infrared camera has provided a tool for the study of heat flow from buildings, which involves thermodynamics (fig. 1.8). The rapid growth in consumer electronics, as seen in the availability of laptop computers, smartphones, and many other "essential" personal paraphernalia, has been made possible by developments in condensed-matter physics. These developments, as well as the development of photovoltaic solar cells (fig 1.9), all involve applications of semiconductors. Particle physicists use particle accelerators to study the interactions of subatomic particles in high-energy collisions. The Large Hadron Collider (fig. 1.10) was used in the discovery of the Higgs Boson.

Science and technology depend on each other for progress. Physics plays an important role in the education and work of engineers, whether they specialize in electrical, mechanical, nuclear, or other engineering fields. In fact, people with physics degrees often work as engineers when they are employed in industry. The lines between physics and engineering, or research and development, often blur. Physicists are generally concerned with developing a fundamental understanding of phenomena, and engineers with applying that understanding to practical tasks or products, but these functions often overlap.

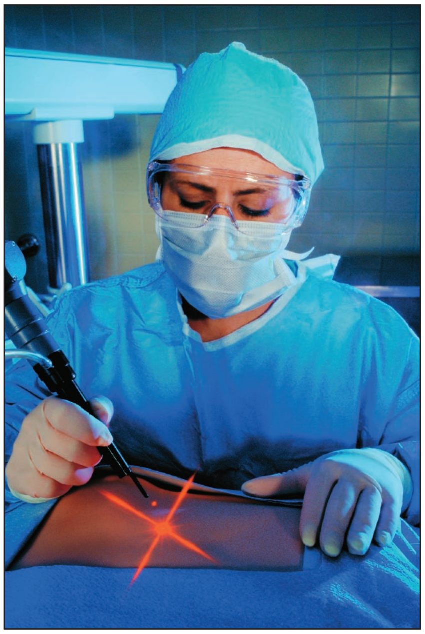


**Figure 1.7** A surgeon using a laser. ©*Corbis/SuperStock RF*

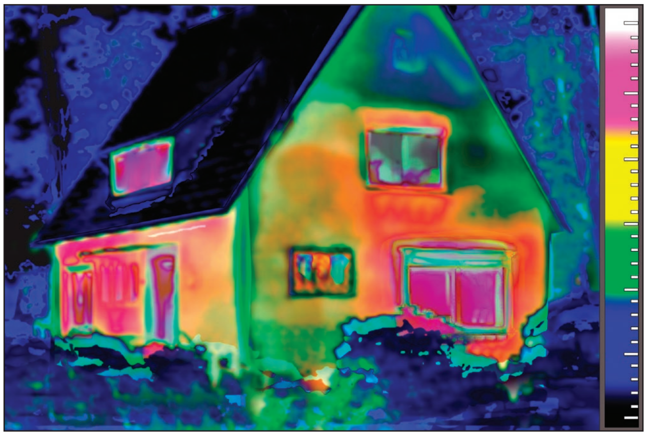


**Figure 1.8** An infrared photograph showing patterns of heat loss from a house is an application of thermodynamics. ©*Dirk Püschel/Getty Images RF*

**Figure 1.9** A power plant at Nellis Air Force Base utilizes photovoltaic solar cells. ©*Stocktrek Images/Getty Images RF*

**Figure 1.10** The Large Hadron Collider (LHC) is an accelerator used to study interactions of subatomic particles at very high energies. It is located at CERN, the European Particle-physics laboratory in Switzerland. ©*Fabrice Coffrini/AFP/Getty Images)*