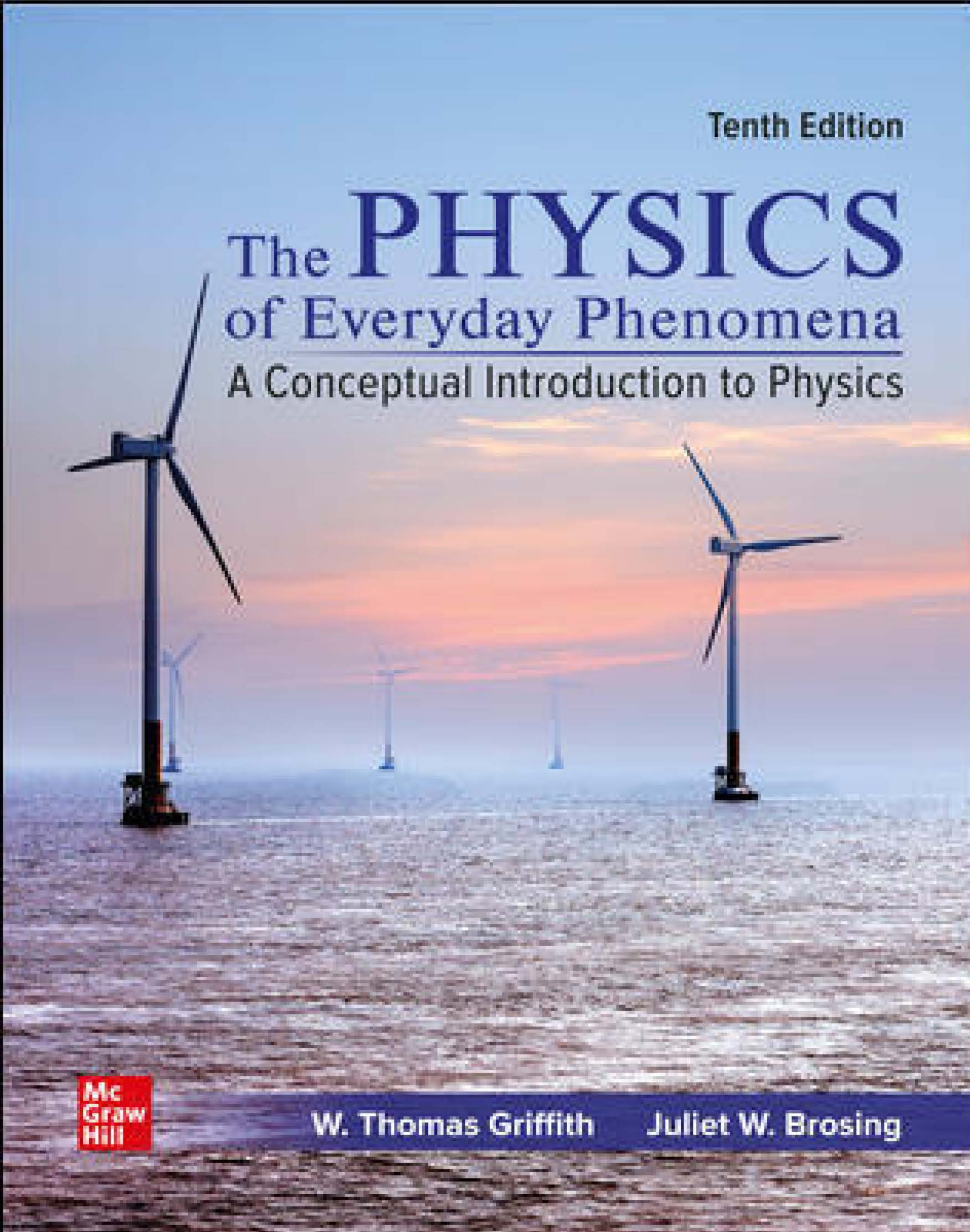

Tenth Edition

The PHYSICS of Everyday Phenomena

A Conceptual Introduction to Physics

W. Thomas Griffith   Juliet W. Brosing

Mc Graw Hill

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Pacific University

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

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 LWI 24 23 22 21

ISBN 978-1-260-71893-5 (bound edition)
MHID 1-260-71893-X (bound edition)
ISBN 978-1-264-12121-2 (loose-leaf edition)
MHID 1-264-12121-0 (loose-leaf edition)

Portfolio Manager: *Beth Bettcher*
Senior Product Developer: *Mary Hurley*
Senior Marketing Manager: *Shannon O'Donnell*
Content Project Managers: *Jane Mohr and Samantha Donisi*
Buyer: *Susan K. Culbertson*
Designer: *Beth Blech*
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Cover Image: *wangsong/123RF*
Compositor: *Aptara®, Inc.*

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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: Tenth edition. | New York, NY : McGraw-Hill Education, [2022]
| Includes index.
Identifiers: LCCN 2020021788 (print) | LCCN 2020021789 (ebook) | ISBN
9781260718935 (hardcover) | ISBN 9781264121212 (spiral bound) | ISBN
9781264121250 (ebook) | ISBN 9781264121267 (ebook other)
Subjects: LCSH: Physics—Textbooks.
Classification: LCC QC23.2 .G75 2022 (print) | LCC QC23.2 (ebook) | DDC
530—dc23
LC record available at https://lccn.loc.gov/2020021788
LC ebook record available at https://lccn.loc.gov/2020021789

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Brief Contents

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, Tom Griffith, and his wife, Sally.
Courtesy of Tom Griffith

Juliet Brosing is now Distinguished University Professor Emeritus at Pacific University in Forest Grove, Oregon, where she taught physics for 30 years. Her research interests included 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 still involve projectiles, lots of noise, and fudge. Even though retired, Dr. Brosing retains contact with her many talented alumni. She now finds time for kayaking, gardening, and, of course, working on this book! Above all, Dr. Brosing is dedicated to helping faculty teach physics with a positive outlook and methods that encourage and benefit students, regardless of their chosen field of study.

The author, Juliet Brosing, and her husband, Keith LeComte, at the Oregon coast with their dog, Walter.
Karla Rumpf

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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 on 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 incorporating the concept videos, narrated by one of the authors, into the Connect question bank. These videos explain how physics is involved in everyday situations, so question content has likewise been authored and enhanced to showcase the everyday application of physics. The Instructor's Manual for each chapter also lists the specific section of the text each video corresponds to, and the videos are then hyperlinked in the eBook and noted in the print text with an icon. These additional guides will help faculty, should they wish to use the videos during class. Each video is no more than 5 minutes long.
- We have developed additional conceptual questions and exercises and made them available as Connect online homework.
- The Instructor's Manual, downloadable from the instructor resources in Connect, has also been improved and describes which PowerPoint slides and which clicker questions go with each section of the text, making it easier for an instructor to prepare for an engaged class period with a minimum of effort. Within the Instructor's Manual, instructors will also find suggestions for demonstrations and discussions.
- For maximum flexibility, the test bank is available in both the Connect question bank and Test Builder. Found in Connect under the Library Tab, Test Builder is a cloud-based tool that enables instructors to format tests that can be printed or administered within a Learning Management System.

In addition to the enhanced digital offerings, we have continued to improve upon the text with the 10th 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 material in the text and added some new conceptual questions and exercises. All odd-numbered exercises have the answers in appendix D in the hard copy of the text, as well as links to the answers in the e-book. Answers to about one-sixth of the conceptual questions are also included in appendix D. Answers to a different one-sixth of the conceptual questions are included as a Student Resource on the Connect instructor resources and may be provided to students at the instructor's discretion. We encourage users to adopt the digital homework system, Connect. The value of this is that parameters in the exercises have been randomized for students. Thus, students spend time discussing *how* to solve the problems, rather than simply focusing on 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—a significant tool to enhance conceptual understanding.

The everyday phenomenon boxes have been praised by many users. We have updated several of these boxes, particularly those in chapters 10 and 18, and have added a new one in chapter 1 (on dealing with proportions). 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 in the Connect instructor resources. 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 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.

Remote Proctoring & Browser-Locking Capabilities

New remote proctoring and browser-locking capabilities, hosted by Proctorio within Connect, provide control of the assessment environment by enabling security options and verifying the identity of the student.

Seamlessly integrated within Connect, these services allow instructors to control students' assessment experience by restricting browser activity, recording students' activity, and verifying students are doing their own work.

Instant and detailed reporting gives instructors an at-a-glance view of potential academic integrity concerns, thereby avoiding personal bias and supporting evidence-based claims.

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.

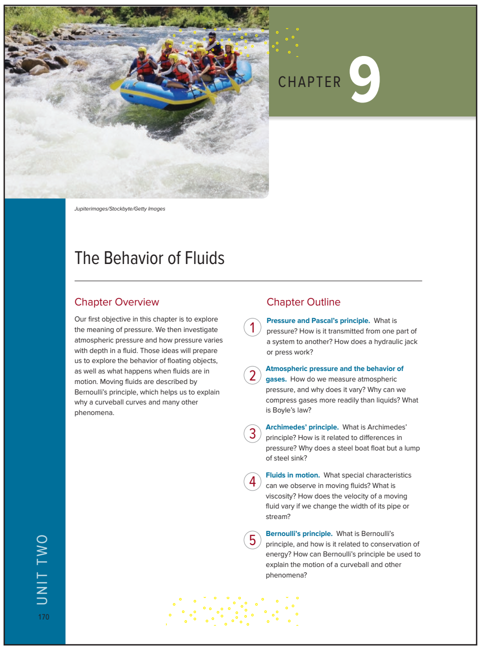
- Connect offers comprehensive service, support, and training throughout every phase of your implementation.
- If you're looking for some guidance on how to use Connect, or want to learn tips and tricks from super users, you can find tutorials as you work. Our Digital Faculty Consultants and Student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



CHAPTER 9

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The Behavior of Fluids

Chapter Overview

Our first objective in this chapter is to explore the meaning of pressure. We then investigate atmospheric pressure and how pressure varies with depth in a fluid. Those ideas will prepare us to explore the behavior of floating objects, as well as what happens when fluids are in motion. Moving fluids are described by Bernoulli's principle, which helps us to explain why a curveball curves and many other phenomena.

Chapter Outline

① **Pressure and Pascal's principle.** What is pressure? How is it transmitted from one part of a system to another? How does a hydraulic jack or press work?

② **Atmospheric pressure and the behavior of gases.** How do we measure atmospheric pressure, and why does it vary? Why can we compress gases more readily than liquids? What is Boyle's law?

③ **Archimedes' principle.** What is Archimedes' principle? How is it related to differences in pressure? Why does a steel boat float but a lump of steel sink?

④ **Fluids in motion.** What special characteristics can we observe in moving fluids? What is viscosity? How does the velocity of a moving fluid vary if we change the width of its pipe or stream?

⑤ **Bernoulli's principle.** What is Bernoulli's principle, and how is it related to conservation of energy? How can Bernoulli's principle be used to explain the motion of a curveball and other phenomena?

UNIT TWO

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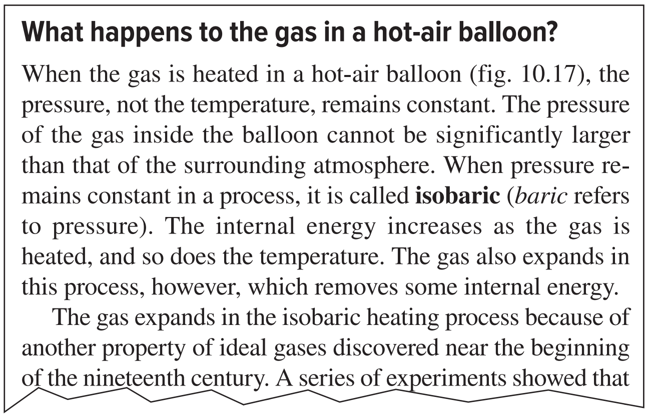
The chapter outlines, questions, and summaries provide a clear framework for the ideas discussed in each chapter. One of the difficulties that students have in learning physics (or any subject) is that they fail to construct the big picture of how things fit together. A consistent chapter framework can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

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.



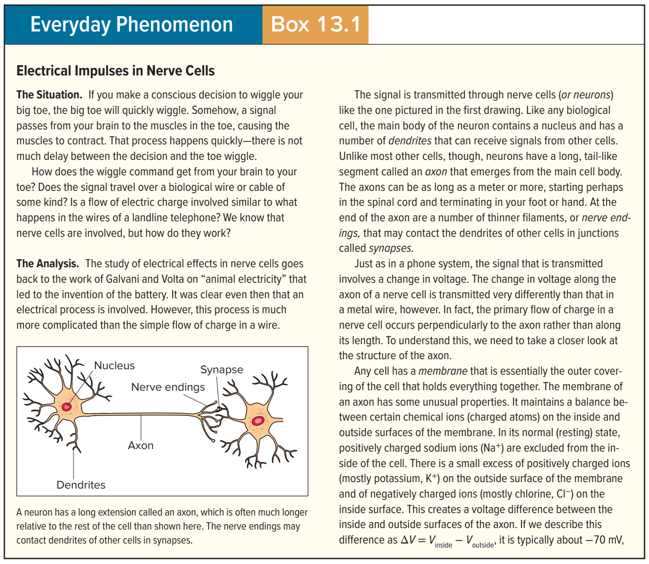
What happens to the gas in a hot-air balloon?

When the gas is heated in a hot-air balloon (fig. 10.17), the pressure, not the temperature, remains constant. The pressure of the gas inside the balloon cannot be significantly larger than that of the surrounding atmosphere. When pressure remains constant in a process, it is called **isobaric** (*baric* refers to pressure). The internal energy increases as the gas is heated, and so does the temperature. The gas also expands in this process, however, which removes some internal energy.

The gas expands in the isobaric heating process because of another property of ideal gases discovered near the beginning of the nineteenth century. A series of experiments showed that

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 Coffeemaker (chapter 1)
Scaling a Recipe (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, Greenhouses, and Global Warming (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)
Television Development (chapter 18)
Smoke Detectors (chapter 19)
What Happened at Fukushima? (chapter 19)
The Twin Paradox (chapter 20)
Holograms (chapter 21)



Everyday Phenomenon **Box 13.1**

Electrical Impulses in Nerve Cells

The Situation. If you make a conscious decision to wiggle your big toe, the big toe will quickly wiggle. Somehow, a signal passes from your brain to the muscles in the toe, causing the muscles to contract. That process happens quickly—there is not much delay between the decision and the toe wiggle.

How does the wiggle command get from your brain to your toe? Does the signal travel over a biological wire or cable of some kind? Is a flow of electric charge involved similar to what happens in the wires of a landline telephone? We know that nerve cells are involved, but how do they work?

The Analysis. The study of electrical effects in nerve cells goes back to the work of Galvani and Volta on "animal electricity" that led to the invention of the battery. It was clear even then that an electrical process is involved. However, this process is much more complicated than the simple flow of charge in a wire.

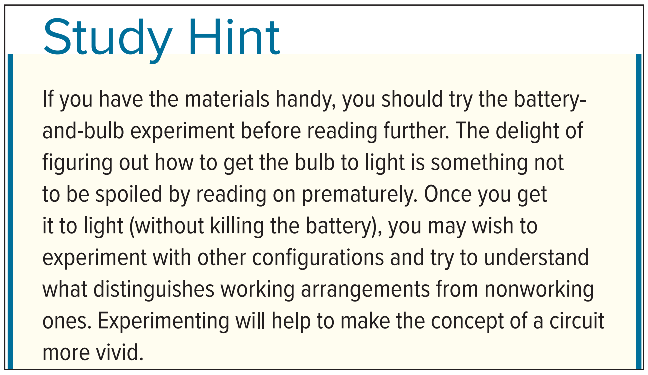
A neuron has a long extension called an axon, which is often much longer relative to the rest of the cell than shown here. The nerve endings may contact dendrites of other cells in synapses.

The signal is transmitted through nerve cells (*or neurons*) like the one pictured in the first drawing. Like any biological cell, the main body of the neuron contains a nucleus and has a number of *dendrites* that can receive signals from other cells. Unlike most other cells, though, neurons have a long, tail-like segment called an *axon* that emerges from the main cell body. The axons can be as long as a meter or more, starting perhaps in the spinal cord and terminating in your foot or hand. At the end of the axon are a number of thinner filaments, or *nerve endings,* that may contact the dendrites of other cells in junctions called *synapses.*

Just as in a phone system, the signal that is transmitted involves a change in voltage. The change in voltage along the axon of a nerve cell is transmitted very differently than that in a metal wire, however. In fact, the primary flow of charge in a nerve cell occurs perpendicularly to the axon rather than along its length. To understand this, we need to take a closer look at the structure of the axon.

Any cell has a *membrane* that is essentially the outer covering of the cell that holds everything together. The membrane of an axon has some unusual properties. It maintains a balance between certain chemical ions (charged atoms) on the inside and outside surfaces of the membrane. In its normal (resting) state, positively charged sodium ions (Na^+) are excluded from the inside of the cell. There is a small excess of positively charged ions (mostly potassium, K^+) on the outside surface of the membrane and of negatively charged ions (mostly chlorine, Cl^-) on the inside surface. This creates a voltage difference between the inside and outside surfaces of the axon. If we describe this difference as $\Delta V = V_{\text{inside}} - V_{\text{outside}}$, it is typically about −70 mV,

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 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 2.4

Sample Exercise: Uniform Acceleration

A car traveling due east with an initial velocity of 10 m/s accelerates for 6 seconds at a constant rate of 4 m/s^2.

a. What is its velocity at the end of this time?
b. How far does it travel during this time?

a. $v_0 = 10$ m/s
$a = 4$ m/s^2
$t = 6$ s
$v = ?$

$$v = v_0 + at$$
$$= 10 \text{ m/s} + (4 \text{ m/s}^2)(6 \text{ s})$$
$$= 10 \text{ m/s} + 24 \text{ m/s}$$
$$= \mathbf{34\ m/s}$$

v = 34 m/s due east

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

$$= (10 \text{ m/s})(6 \text{ s}) + \frac{1}{2}(4 \text{ m/s}^2)(6 \text{ s})^2$$
$$= 60 \text{ m} + (2 \text{ m/s}^2)(36 \text{ s}^2)$$
$$= 60 \text{ m} + 72 \text{ m} = \mathbf{132\ m}$$

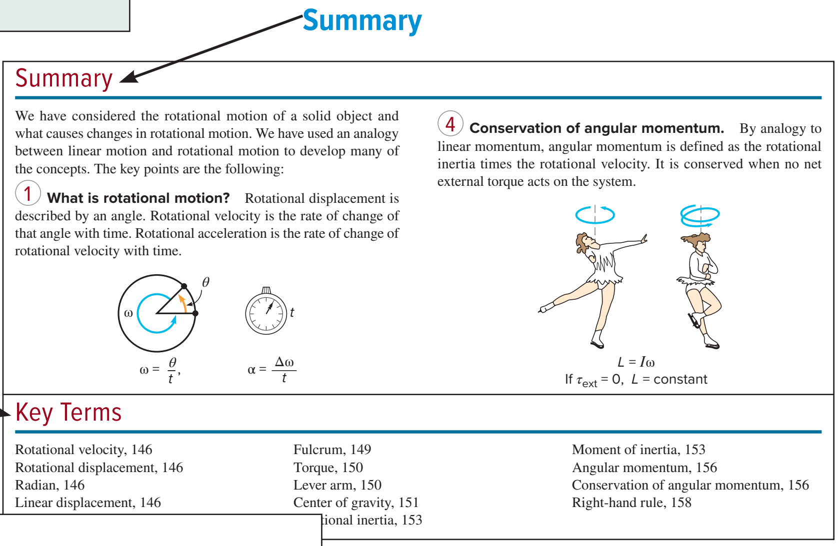
Debatable Issues provide open-ended, opinion questions on—but not limited to—energy and environmental issues to be used as class discussion, as writing assignments, and/or for Internet forums. Notes on discussion ideas and results are included in the instructor's manual.

Debatable Issue

France gets more than 75% of its power from nuclear energy and 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

We have considered the rotational motion of a solid object and what causes changes in rotational motion. We have used an analogy between linear motion and rotational motion to develop many of the concepts. The key points are the following:

① **What is rotational motion?** Rotational displacement is described by an angle. Rotational velocity is the rate of change of that angle with time. Rotational acceleration is the rate of change of rotational velocity with time.

$\omega = \frac{\theta}{t}$, $\alpha = \frac{\Delta\omega}{t}$

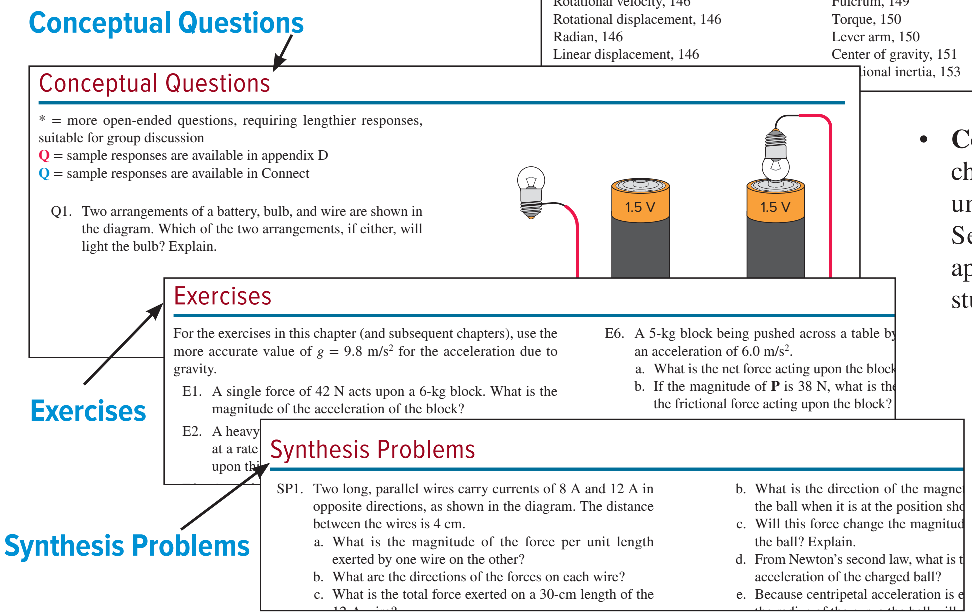
④ **Conservation of angular momentum.** By analogy to linear momentum, angular momentum is defined as the rotational inertia times the rotational velocity. It is conserved when no net external torque acts on the system.

$L = I\omega$
If $\tau_{ext} = 0$, L = constant

Key Terms

Rotational velocity, 146	Fulcrum, 149	Moment of inertia, 153
Rotational displacement, 146	Torque, 150	Angular momentum, 156
Radian, 146	Lever arm, 150	Conservation of angular momentum, 156
Linear displacement, 146	Center of gravity, 151	Right-hand rule, 158
	ional inertia, 153	

- **Key terms** are page-referenced to where students can find the terms defined in context.



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. Two arrangements of a battery, bulb, and wire are shown in the diagram. Which of the two arrangements, if either, will light the bulb? Explain.

Exercises

For the exercises in this chapter (and subsequent chapters), use the more accurate value of $g = 9.8$ m/s^2 for the acceleration due to gravity.

E1. A single force of 42 N acts upon a 6-kg block. What is the magnitude of the acceleration of the block?
E2. A heavy
at a rate
upon thi

E6. A 5-kg block being pushed across a table by
an acceleration of 6.0 m/s^2.
a. What is the net force acting upon the block
b. If the magnitude of **P** is 38 N, what is the
the frictional force acting upon the block?

Synthesis Problems

SP1. Two long, parallel wires carry currents of 8 A and 12 A in opposite directions, as shown in the diagram. The distance between the wires is 4 cm.
a. What is the magnitude of the force per unit length exerted by one wire on the other?
b. What are the directions of the forces on each wire?
c. What is the total force exerted on a 30-cm length of the

b. What is the direction of the magne
the ball when it is at the position sh
c. Will this force change the magnitud
the ball? Explain.
d. From Newton's second law, what is t
acceleration of the charged ball?
e. Because centripetal acceleration is e

- **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** 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.

> *"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

Instructor Resources

In addition, instructor resources, accessed by the library tab in Connect, provide instructors with useful tools designed to help improve student understanding of the material presented in the text and class and other tools designed to help ease the time burdens of the course by providing valuable presentation and preparation tools.

Accessible PowerPoint Lectures
Instructor's Manual
Sample Syllabi
Clicker Questions
PowerPoints and Image Files of Art and Photos from the Text
Test Bank
Formula Summaries
Physics Interactives
Concept Videos
Practice Problems

For sharing with students:
- Author-narrated videos illustrating physics in everyday situations (noted in text with a video icon) ▶
- Student Solutions Manual
- Additional Solutions and Answers

Personal Response Systems

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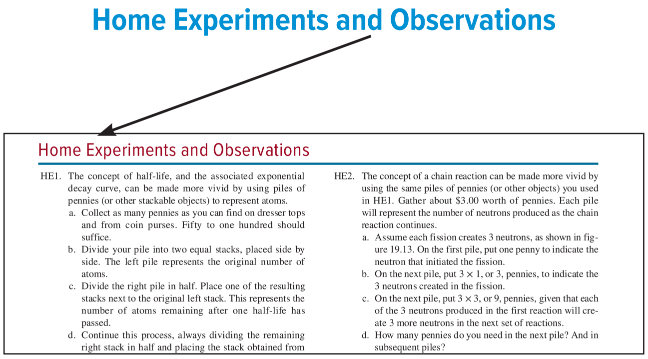
Home Experiments and Observations

Home Experiments and Observations

HE1. The concept of half-life, and the associated exponential decay curve, can be made more vivid by using piles of pennies (or other stackable objects) to represent atoms.
  a. Collect as many pennies as you can find on dresser tops and from coin purses. Fifty to one hundred should suffice.
  b. Divide your pile into two equal stacks, placed side by side. The left pile represents the original number of atoms.
  c. Divide the right pile in half. Place one of the resulting stacks next to the original left stack. This represents the number of atoms remaining after one half-life has passed.
  d. Continue this process, always dividing the remaining right stack in half and placing the stack obtained from

HE2. The concept of a chain reaction can be made more vivid by using the same piles of pennies (or other objects) you used in HE1. Gather about $3.00 worth of pennies. Each pile will represent the number of neutrons produced as the chain reaction continues.
  a. Assume each fission creates 3 neutrons, as shown in figure 19.13. On the first pile, put one penny to indicate the neutron that initiated the fission.
  b. On the next pile, put 3 × 1, or 3, pennies, to indicate the 3 neutrons created in the fission.
  c. On the next pile, put 3 × 3, or 9, pennies, given that each of the 3 neutrons produced in the first reaction will create 3 more neutrons in the next set of reactions.
  d. How many pennies do you need in the next pile? And in subsequent piles?

Computerized Test Banks Online

For maximum flexibility, the test bank is available in both the Connect question bank and Test Builder. Found in Connect under the Library Tab, Test Builder is a cloud-based tool that enables instructors to format tests that can be printed or administered within a Learning Management System.

Acknowledgments

A large number of people have contributed to this 10th edition, either directly or indirectly. We extend particular thanks to those who participated in reviews of the previous editions. Their thoughtful suggestions have had a direct impact on 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 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. Our 10th edition accuracy checker, Michael Faux of SUNY Oneonta, also provided constructive criticisms and many suggestions for improvement.

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.

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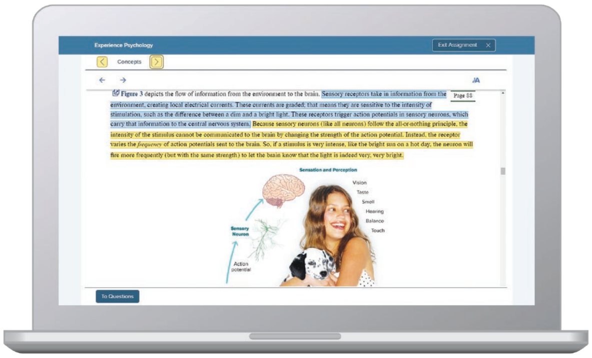

Figure 3 depicts the flow of information from the environment to the brain. Sensory receptors take in information from the environment, creating local electrical currents. These currents are graded; that means they are sensitive to the intensity of stimulation, such as the difference between a dim and a bright light. These receptors trigger action potentials in sensory neurons, which carry that information to the central nervous system. Because sensory neurons (like all neurons) follow the all-or-nothing principle, the intensity of the stimulus cannot be communicated to the brain by changing the strength of the action potential. Instead, the receptor varies the *frequency* of action potentials sent to the brain. So, if a stimulus is very intense, like the bright sun on a hot day, the neuron will fire more frequently (but with the same strength) to let the brain know that the light is indeed very, very bright.

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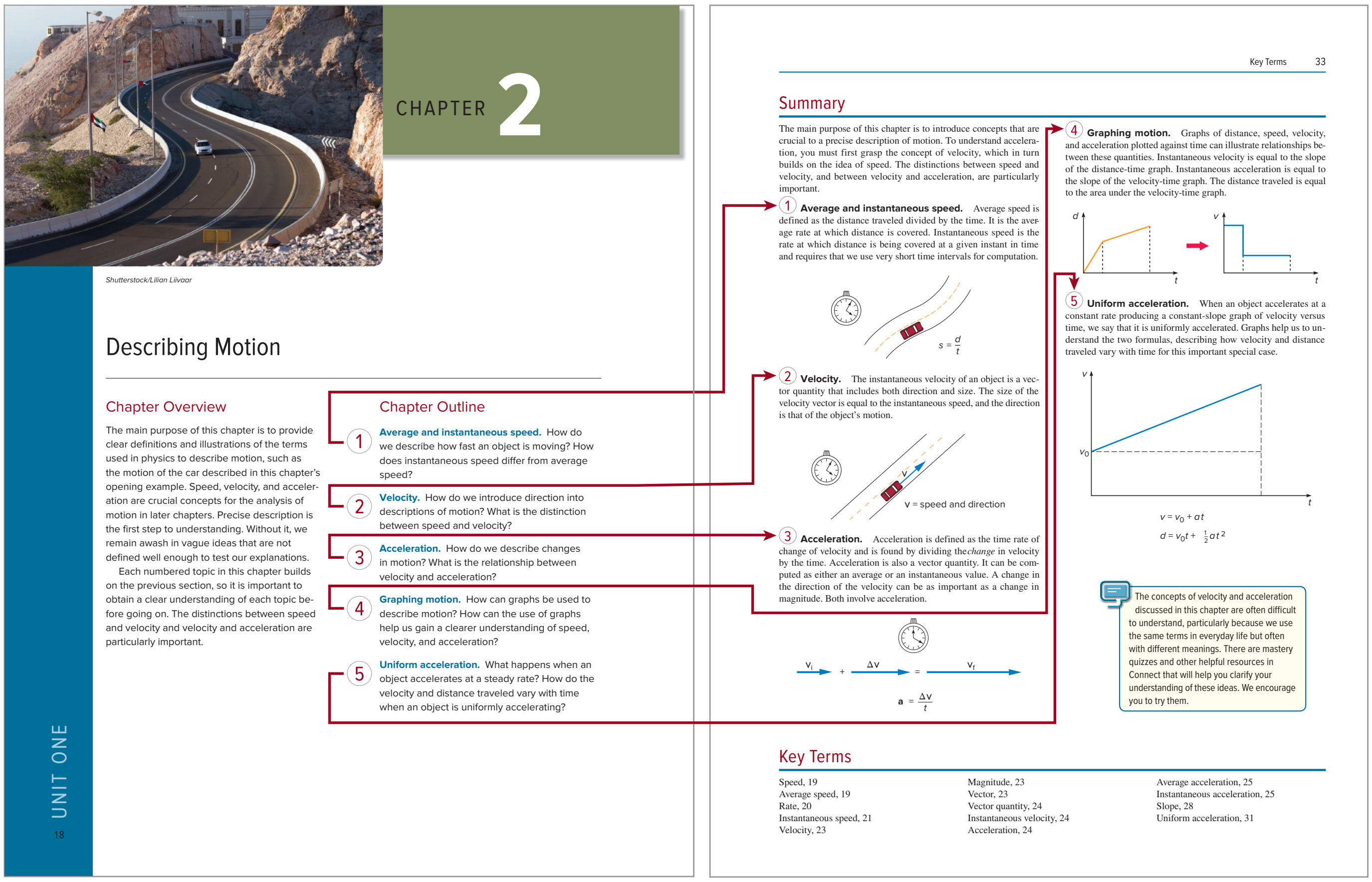
Secrets to Success in Studying Physics

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.



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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?

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.

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.

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.

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.

$$v = v_0 + at$$

$$d = v_0 t + \frac{1}{2}at^2$$

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

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

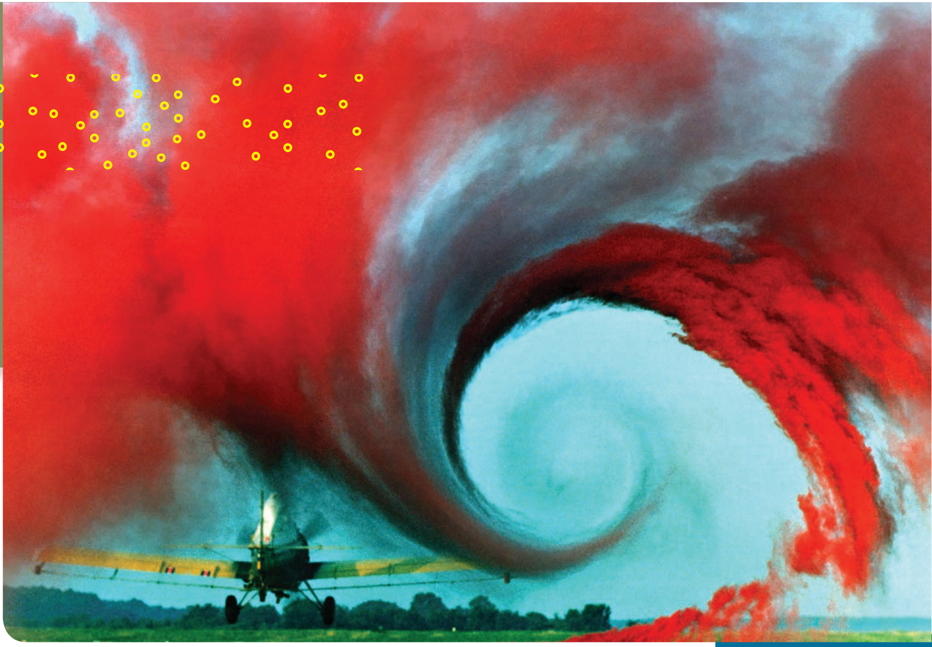
Reading or talking about physical ideas is useful, but there is no substitute for hands-on experience with the phenomena. You already have a wealth of experience with many of these phenomena, but you probably have not related it to the physical concepts you will be learning. Seeing things in new ways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

CHAPTER 1



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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 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 rainbow 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 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 can you do to understand and coherently discuss energy issues?

How is energy involved in the global warming debate?

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 timescale. It is a geologic flash in the pan. (See fig. 1.2.)

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.

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.

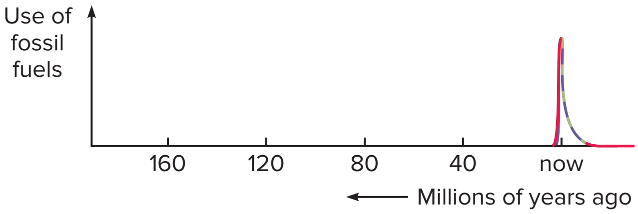

Figure 1.2 A schematic sketch of our use of fossil fuels on a geologic timescale. Coal, oil, and natural gas were produced from 40 million to 200 million years ago.

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.

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. 1.3), 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 does 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.

Figure 1.3 Are nuclear power plants our salvation or relics of the past? *Steve Allen/Brand X Pictures/Alamy Stock Photo*

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 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 return 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

Figure 1.4 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*

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. 1.4). 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 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.

What is the scientific method?

Is there something we can 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

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.

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*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.

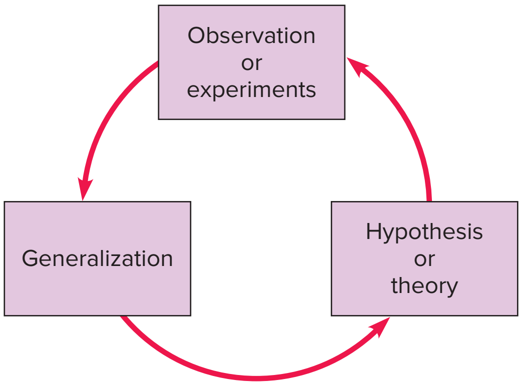


Figure 1.5 The scientific method cycles back to observations or experiments as we seek to test our hypotheses or theories. Communication with peers is involved in all stages of the process.

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. 1.5).

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 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 coffeemaker described in everyday phenomenon box 1.1 provides an example of scientific reasoning applied to ordinary troubleshooting.

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!

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

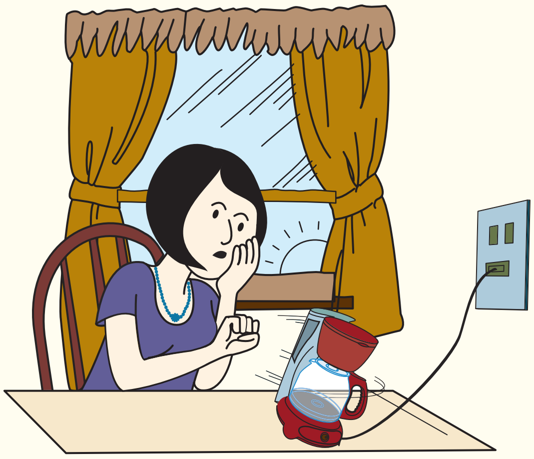
Where does physics fit within the sciences? Since this book is about physics, rather than biology, chemistry, geology, or some other science, it is reasonable to ask where we draw the lines between the disciplines. It is not possible, however, to make sharp distinctions among the disciplines or to provide 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.

Everyday Phenomenon Box 1.1

The Case of the Malfunctioning Coffeemaker

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, which 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 coffeemaker 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 coffeemaker has blown.
e. A wire has become 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 coffeemaker 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 coffeemaker will not help.

The appliance 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 coffeemaker or the panel where the power cord comes in. (You must unplug the appliance 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.

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 the twentieth 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 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 1.6, fig. 1.7, fig. 1.8, and fig. 1.9) illustrate characteristic activities or applications

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.

Figure 1.6 A surgeon using a laser. *Larry Mulvehill/Corbis/SuperStock*

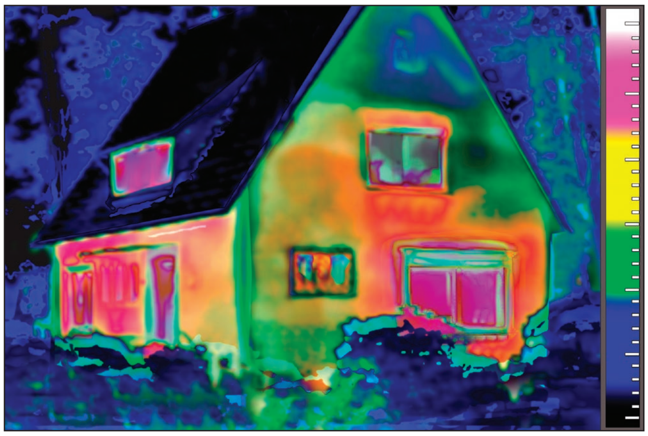


Figure 1.7 An infrared photograph showing patterns of heat loss from a house is an application of thermodynamics. *Dirk Püschel/Hemera/Getty Images*

Figure 1.8 A power plant at Nellis Air Force Base utilizes photovoltaic solar cells. *Stocktrek Images/Getty Images*

Figure 1.9 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*

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. 1.6). The development of the infrared camera has provided a tool for the study of heat flow from buildings, which involves thermodynamics (fig. 1.7). 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 1.8), 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. 1.9) was used in the discovery of the Higgs Boson in 2012.

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.

One final point: Physics is fun. Understanding how a bicycle works or how a rainbow is formed has an appeal that anyone can appreciate. The thrill of gaining insight into the workings of the universe can be experienced at any level. In this sense, we can all be physicists.

> Physics is the study of the basic characteristics of matter and its interactions. It is the most fundamental of the sciences; many other sciences build on ideas from physics. The major subfields of physics are mechanics, electricity and magnetism, optics, thermodynamics, atomic and nuclear physics, particle physics, and condensed-matter physics. Physics plays an important role in engineering and technology, but the real fun of physics comes from understanding how the universe works.

1.4 The Role of Measurement and Mathematics in Physics

If you go into your college library, find a volume of *Physical Review* or some other major physics journal, and open it at random, you are likely to find a page with many mathematical symbols and formulas. It would probably be incomprehensible to you. In fact, even many physicists who are not specialists in the particular subfield covered by the article might have difficulty making sense of that page, because they would not be familiar with the particular symbols and definitions.

Why do physicists make such extensive use of mathematics in their work? Is knowledge of mathematics essential to understanding the ideas being discussed? Mathematics is a compact language for representing the ideas of physics that makes it easier to precisely state and manipulate the relationships between the quantities that we measure in physics. Once you are familiar with the language, its mystery disappears and its usefulness becomes more obvious. Still, this book uses mathematics in a very limited manner, because most ideas of physics can be discussed without extensive use of mathematics.