FIFTH EDITION

PHYSICS

Alan Giambattista

McGraw Hill Education

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Physics

Alan Giambattista

Cornell University

McGraw Hill Education

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About the Author

Alan Giambattista hails from northern New Jersey. His teaching career got an early start when his fourth-grade teacher, Anne Berry, handed the class over to him to teach a few lessons about atoms and molecules. At Brigham Young University, he studied piano performance and physics. After graduate work at Cornell University, he joined the physics faculty and has taught introductory physics there for nearly three decades.

Alan still appears in concert regularly as a pianist and harpsichordist. When the long upstate New York winter is finally over, he is eager to get out on Cayuga Lake's waves of blue for Sunday sailboat races. Alan met his wife Marion in a singing group and they have been making beautiful music together ever since. They live in an 1824 parsonage built for an abolitionist minister, which is now surrounded by an organic dairy farm. Besides taking care of the house, cats, and gardens, they love to travel together, especially to Italy. They also love to spoil their adorable grandchildren, Ivy and Leo.

Photo by Melvin Cabili

Dedication

For Ivy and Leo

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Preface

Physics is intended for a two-semester college course in introductory physics using algebra and trigonometry. The main goals for this book are:

- to present the basic concepts of physics that students need to know for later courses and future careers,
- to emphasize that physics is a tool for understanding the real world, and
- to teach transferable problem-solving skills that students can use throughout their lives.

NEW TO THE FIFTH EDITION

Although the fundamental philosophy of the book has not changed, many improvements have been made based on detailed feedback from instructors and students using the previous edition. Some of the most important updates include:

- The comprehensive math review, found in **Appendix A,** has been expanded for this edition. A new section **A.8 (Sinusoidal Functions of Time)** provides support for important topics such as oscillations, waves, Faraday's law, and interference. **Section A.6 (Geometry)** has been rewritten to emphasize the skills most relevant to physics problems. **Math skills** have been added to the **Concepts and Skills to Review** on the chapter opener pages. New references to **Appendix A** have been added to the text.
- The visual presentation has been streamlined. The content of tips and warnings found in marginal icons and text highlighting, has been moved into **Problem-Solving Strategy** boxes and/or into the end-of-chapter **Master the Concepts** boxes, as appropriate.
- **Concepts and Skills to Review** lists are now more prominently featured on the chapter opener page.
- Many of the figure legends have been expanded to help students learn more from the illustrations.

Notable revisions to the text include:

- **Example 1.9** has been expanded to demonstrate an alternative method of performing dimensional analysis. New problems have been added to Chapter 1 to give students more practice using ratios and proportions.
- **Section 3.6** on relative velocity and reference frames has been revised to emphasize that velocity of A relative to B is the vector difference of the two velocities as measured in a common reference frame.
- **Example 4.9** has been rewritten to focus more clearly on Newton's third law.
- **Section 4.10** (Apparent Weight) no longer develops a formula for apparent weight. Instead, the section emphasizes fundamental skills (drawing an FBD and analyzing the forces) and summarizes the procedure in a new Problem-Solving Strategy box.
- In **Chapter 5**, the Problem-Solving Strategies for uniform and nonuniform circular motion have been revised to show a parallel structure. A new figure shows the forces acting on a car traveling around a banked curve.

- **Chapter 6** has new Problem-Solving Strategies for work done by a constant force and for mechanical energy.
- In **Section 8.2**, the discussion of the lever arm has been clarified.
- **Section 11.5** (Mathematical Description of a Wave) has been rewritten to be more accessible.
- **Sections 12.7 and 12.8** (Beats, The Doppler Effect) have been rewritten. Formulating the Doppler effect in terms of relative velocities makes an arbitrary sign convention unnecessary.
- **Sections 15.5–15.7** contain improved explanations of heat engines and heat pumps.
- A table of circuit symbols is now included at the end of **Chapter 18**.
- **Section 19.10** has been rewritten to provide a more complete description of paramagnetism and diagmagnetism.
- **Chapter 20**'s treatment of inductance has been streamlined, with the quantitative material on mutual inductance moved into an online supplement. Chapter 20 has gained 10 new end-of-chapter problems on Faraday's law.
- **Section 22.7** now includes a description of circular polarization.
- New **Figure 23.47** is a ray diagram for the formation of a virtual image by a converging lens.
- **Section 24.3** describes astigmatism of the eye. **Section 24.7** contains an expanded explanation of lens aberrations.
- **Chapter 25** simplifies the discussion of phase differences for constructive and destructive interference.
- **Chapter 30** mentions the observation of gravitational waves by the LIGO collaboration.

A CONCEPTS-FIRST APPROACH

Some students approach introductory physics with the idea that physics is just the memorization of a long list of equations and the ability to plug numbers into those equations. *Physics* emphasizes that a relatively small number of basic physics concepts are applied to a wide variety of situations. Physics education research has shown that students do not automatically acquire conceptual understanding; the concepts must be explained and the students given a chance to grapple with them. The presentation in *Physics* blends conceptual understanding with analytical skills. The "concepts-first" approach helps students develop intuition about how physics works; the "formulas" and problem-solving techniques serve as *tools for applying the concepts.* The **Conceptual Examples** and **Conceptual Practice Problems** in the text and a variety of ranking tasks and **Conceptual** and **Multiple-Choice Questions** at the end of each chapter give students a chance to check and to enhance their conceptual understanding.

INTRODUCING CONCEPTS INTUITIVELY

Key concepts and quantities are introduced in an informal and intuitive way, using a concrete example to establish why the concept or quantity is useful. Concepts motivated in this way are easier for students to grasp and remember than are concepts introduced by seemingly arbitrary, formal definitions.

For example, in Chapter 8, the idea of rotational inertia emerges in a natural way from the concept of rotational kinetic energy. Students can understand that a rotating rigid body has kinetic energy due to the motion of its particles. The text discusses why it is useful to be able to write this kinetic energy in terms of a single quantity common to all the particles (the angular speed), rather than as a sum involving particles with many different speeds. When students understand why rotational inertia is defined the way it is, they are better prepared to move on to the more difficult concepts of torque and angular momentum.

The text avoids presenting definitions or formulas without motivation. When an equation is not derived in the text, a conceptual explanation or a plausibility argument is given. For example, Section 9.9 introduces Poiseuille's law with two identical pipes in series to show why the volume flow rate must be proportional to the pressure drop per unit length. The text then discusses why $\Delta V/\Delta t$ is proportional to the fourth power of the radius (rather than to r^2, as it would be for an ideal fluid).

Similarly, the definitions of the displacement and velocity vectors can seem arbitrary and counterintuitive to students if introduced without any motivation. Therefore, presentation of the kinematic quantities is preceded by an introduction to Newton's laws, so students know that forces determine how the state of motion of an object changes. The conceptual groundwork for a concept is particularly important when its name is a common English word such as *velocity* or *work*.

DESIGNED FOR ACTIVE LEARNING

Previous editions of *Physics* have been tested for over 15 years in Cornell's nontraditional course, where students rely on the textbook as their primary source of information because there are no lectures. The text is therefore well suited to use in flipped classrooms and other nontraditional course formats. Nonetheless, completeness and clarity are equally advantageous when the book is used in a more traditional classroom setting. *Physics* frees the instructor from having to try to "cover" everything. The instructor can then tailor class time to more important student needs—reinforcing difficult concepts, working through Example problems, engaging the students in peer instruction and cooperative learning activities, describing applications, or presenting demonstrations.

WRITTEN IN A CLEAR AND FRIENDLY STYLE

Physics was developed specifically for the algebra/trig-based course; it's not a spinoff of a calculus-based text for engineers or physics majors. The writing is intended to be down-to-earth and conversational in tone—the kind of language an experienced teacher uses when sitting at a table working one-on-one with a student. Students should feel confident that they can learn by studying the textbook.

Although learning correct physics terminology is essential, *Physics* avoids *unnecessary* jargon—terminology that just gets in the way of the student's understanding. For example, the term *centripetal force* does not appear in the book, since its use sometimes leads students to add a spurious "centripetal force" to their free-body diagrams. *Radial component of acceleration* is preferred over *centripetal acceleration* because it is less likely to introduce or reinforce misconceptions.

MCAT® SUPPORT

Coverage of topics such as mechanical advantage, turbulence, surface tension, attenuation of sound waves, magnetic materials, and circular polarization has been expanded or added to this edition based on the 2015 revision of the MCAT® exam. Students who plan to take the MCAT® can rest assured that *all* the physics topics on that exam are included in the text.

PROVIDING STUDENTS WITH THE TOOLS THEY NEED

Problem-Solving Approach

Problem-solving skills are central to an introductory physics course. These skills are illustrated in the Example problems. Lists of problem-solving strategies can be useful; *Physics* presents such strategies when appropriate. However, the most elusive skills—perhaps the most important ones—are subtle points that defy being put into a neat list. To develop real problem-solving expertise, students must learn how to think critically and analytically. Problem solving is a multidimensional, complex process; an algorithmic approach is not adequate to instill real problem-solving skills.

An important problem-solving skill that many students need to practice is extracting information from a graph or sketching a graph without plotting individual data points. Graphs often help students visualize physical relationships more clearly than they can with algebra alone. Graphs and sketches are emphasized in the text, in worked examples, and in the problems.

Strategy Each Example begins with a discussion—in language that the students can understand—of the *strategy* to be used in solving the problem. The strategy illustrates the kind of analytical thinking students must do when attacking a problem: How do I decide what approach to use? What laws of physics apply to the problem and which of them are *useful* in this solution? What clues are given in the statement of the question? What information is implied rather than stated outright? If there are several valid approaches, how do I determine which is the most efficient? What assumptions can I make? What kind of sketch or graph might help me solve the problem? Is a simplification or approximation called for? If so, how can I tell if the simplification is valid? Can I make a preliminary estimate of the answer? Only after considering these questions can the student effectively solve the problem.

Solution Next comes the detailed *solution* to the problem. Explanations are intermingled with equations and step-by-step calculations to help the student understand the approach used to solve the problem.

Discussion The numerical or algebraic answer is not the end of the problem; the Examples end with a *discussion.* Students must learn how to determine whether their answer is consistent and reasonable by checking the order of magnitude of the answer, comparing the answer with a preliminary estimate, verifying the units, and doing an independent calculation when more than one approach is feasible. When several different approaches are possible, the discussion looks at the advantages and disadvantages of each approach. The discussion generalizes the problem-solving techniques used in the solution, examines special cases, and considers "what if" scenarios.

Practice Problem After each Example, a Practice Problem gives students a chance to gain experience using the same physics principles and problem-solving tools. By comparing their answers with those provided at the end of each chapter, students can gauge their understanding and decide whether to move on to the next section.

Using Approximation, Estimation, and Proportional Reasoning

Physics is forthright about the constant use of simplified models and approximations in solving physics problems. One of the most difficult aspects of problem solving that students need to learn is that some kind of simplified model or approximation is usually required. The text discusses how to know when it is reasonable to ignore friction, treat g as constant, ignore viscosity, treat a charged object as a point charge, or ignore diffraction.

Some Examples and Problems require the student to make an estimate—a useful skill both in physics problem solving and in many other fields. Proportional reasoning is used as not only an elegant shortcut but also as a means to understanding patterns. Examples and problems frequently use percentages and ratios to give students practice in using and understanding them.

Helping Students See the Relevance of Physics in Their Lives

Students in an introductory college physics course have a wide range of backgrounds and interests. To stimulate interest in physics, the text describes many applications relevant to students' lives and aligned with their interests. Examples and end-of-chapter problems that involve applications help students learn that they can answer questions *of interest to them* using physics concepts and skills. The text, Examples, and end-of-chapter problems draw from the everyday world; from familiar technological applications; and from other fields, such as biology, medicine, archaeology, astronomy, sports, environmental science, and geophysics. An icon ( ) identifies applications from the biological or medical sciences.

Everyday Physics Demos give students an opportunity to explore and see physics principles operate in their everyday lives. These activities are chosen for their simplicity and for their effectiveness in demonstrating physics principles.

Each **Chapter Opener** includes a photo and vignette, designed to capture student interest and maintain it throughout the chapter. The vignette describes the situation shown in the photo and asks the student to consider the relevant physics. The vignette topic is then discussed at the appropriate place within the chapter text.

Focusing on the Concepts

A marginal **Connections** box helps students understand that what may seem like a new concept may really be an extension, application, or specialized form of a concept previously introduced. The goal is for students to view physics as a small set of fundamental concepts that can be applied in many different situations, rather than as a collection of loosely related facts or equations. By identifying areas where important concepts are revisited, the Connections return the focus to core concepts.

The exercises in the **Review & Synthesis** sections help students see how the concepts in the previously covered group of chapters are interrelated. These exercises are also intended to help students prepare for tests, in which they must solve problems without having the section or chapter title given as a clue.

Checkpoint questions encourage students to pause and test their understanding of the concept explored within the current section. The answers to the Checkpoints are found at the end of the chapter so that students can confirm their knowledge without jumping too quickly to the provided answer.

Support for Essential Math Skills

In an introductory college physics course, students need to be confident using algebra, geometry, and trigonometry to solve problems. Weak math skills present a major obstacle to success in the course. Instructors seldom (if ever) feel they have enough class time to do enough math review. To help students review on their own and to serve as a comprehensive reference, *Physics* provides an exceptionally detailed **Mathematics Review** (Appendix A). For the fifth edition, more frequent references to Appendix A have been added to the text, especially in the early chapters, to encourage students to use the Appendix to reinforce their math skills. Appendix A has been expanded to include a new section on Sinusoidal Functions of Time.

While revising the Mathematics Review, the author also contributed to a major revision of the ALEKS® *Math Prep for College Physics* course by selecting learning objectives that align with the specific math skills most used in college physics.

Student Solutions Manual

The *Student Solutions Manual* contains complete worked-out solutions to selected end-of-chapter problems and questions, and to selected Review & Synthesis problems. The solutions in this manual follow the problem-solving strategy outlined in the text's Examples and also guide students in creating diagrams for their own solutions.

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- **Photos** The photos collection contains digital files of photographs from the text, which can be reproduced for multiple classroom uses.
- **Workbook** The workbook contains questions and ideas for classroom exercises that will get students thinking about physics in new and comprehensive ways. Students are led to discover physics for themselves, leading to a deeper intuitive understanding of the material.
- **Lecture PowerPoints** Ready-made presentations combine art and lecture notes for each chapter of the text.

- **Test Bank** A comprehensive bank of test questions that accompanies *Physics* is available for instructors to create their own quizzes and exams. These same questions are also available and assignable through Connect for online tests.
- **Instructor's Resource Guide** The guide includes many unique assets for instructors, such as demonstrations, suggested reform ideas from physics education research, and ideas for incorporating just-in-time teaching techniques.
- **Instructor's Solutions Manual** The accompanying Instructor's Solutions Manual includes answers to the end-of-chapter Conceptual Questions and complete, worked-out solutions for all the end-of-chapter Problems from the text.

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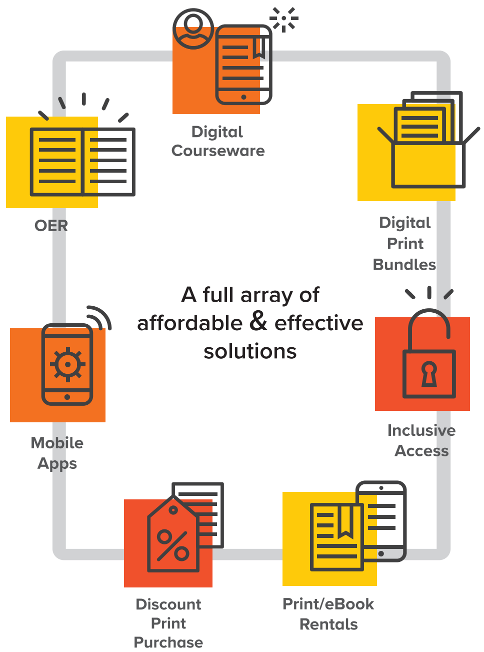

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CHAPTER

1

Introduction

Source:NASA/JPL-Caltech/MSSS

Concepts & Skills to Review

- **math skills**: review of algebra, geometry, and trigonometry (Appendices A.1, A.6, A.7)
- **math skills**: graphs of linear functions (Appendix A.2)
- **math skills**: exponents (Appendix A.4)
- **math skills**: proportions and ratios (Appendix A.5)

SELECTED BIOMEDICAL APPLICATIONS

- Bone density and osteoporosis (Example 1.1)
- Red blood cell count (Practice Problem 1.1)
- Surface area of alveoli in the lung (Example 1.7)
- Estimating the surface area of the human body (Example 1.10)
- Blood vessels and blood flow rates (Problems 13, 14, 27, 37, 42, 75)
- Mass dependence of metabolic rates (Problem 5)
- Speed of a nerve impulse (Problem 33)
- Sizes of organisms, xylem vessels, cells, viruses, and viroids (Problems 14, 27, 70–73)

NASA's Mars rover *Curiosity* landed on the surface of Mars in August 2012. One of the mission's primary objectives was to determine whether Mars ever had an environment capable of supporting microbial life. This photo taken by *Curiosity* shows a rock outcrop that contains rounded pieces of gravel. The size, shape, and composition of the gravel led scientists to conclude that a stream once flowed here.

NASA's many successful missions to Mars have sent back a wealth of geologic data. However, in 1998, a simple mistake caused the loss of the *Mars Climate Orbiter* as it entered orbit around Mars. In this chapter, you will learn how to avoid making this same mistake.

1.1 WHY STUDY PHYSICS?

Physics is the branch of science that describes matter, energy, space, and time at the most fundamental level. Whether you are planning to study biology, architecture, medicine, music, chemistry, or art, some principles of physics are relevant to your field.

Physicists look for patterns in the physical phenomena that occur in the universe. They try to explain what is happening, and they perform experiments to see if the proposed explanation is valid. The goal is to find the most basic laws that govern the universe and to formulate those laws in the most precise way possible.

The study of physics is valuable for several reasons:

Figure 1.1 A patient being prepared for magnetic resonance imaging (MRI). MRI provides a detailed image of the internal structures of the patient's body.

- Since physics describes matter and its basic interactions, all natural sciences are built on a foundation of the laws of physics. A full understanding of chemistry requires a knowledge of the physics of atoms. A full understanding of biological processes in turn is based on the underlying principles of physics and chemistry. Centuries ago, the study of *natural philosophy* encompassed what later became the separate fields of biology, chemistry, geology, astronomy, and physics. Today there are scientists who call themselves biophysicists, chemical physicists, astrophysicists, and geophysicists, demonstrating how thoroughly the sciences are intertwined.
- In today's technological world, many important devices can be understood correctly only with a knowledge of the underlying physics. Just in the medical world, think of laser surgery, magnetic resonance imaging (Fig. 1.1), instant-read thermometers, x-ray imaging, radioactive tracers, heart catheterizations, sonograms, pacemakers, microsurgery guided by optical fibers, ultrasonic dental drills, and radiation therapy.
- By studying physics, you acquire skills that are useful in other disciplines. These include thinking logically and analytically, solving problems, making simplifying assumptions, constructing mathematical models, using valid approximations, and making precise definitions.
- Society's resources are limited, so it is important to use them in beneficial ways and not squander them on scientifically impossible projects. Political leaders and the voting public are too often led astray by a lack of understanding of scientific principles. Can a nuclear power plant supply energy safely to a community? What is the truth about global climate change, the ozone hole, and the danger of radon in the home? By studying physics, you learn some of the basic scientific principles and acquire some of the intellectual skills necessary to ask probing questions and to formulate informed opinions on these important matters.
- Finally, we hope that by studying physics, you develop a sense of the beauty of the fundamental laws that describe the universe.

1.2 TALKING PHYSICS

Some of the words used in physics are familiar from everyday speech. This familiarity can be misleading, however, since the scientific definition of a word may differ considerably from its common meaning. In physics, words must be precisely defined so that anyone reading a scientific paper or listening to a science lecture understands exactly what is meant. Some of the basic defined quantities, whose names are also words used in everyday speech, include time, length, force, velocity, acceleration, mass, energy, momentum, and temperature.

In everyday language, *speed* and *velocity* are synonyms. In physics, there is an important distinction between the two. In physics, *velocity* includes the *direction* of motion as well as the distance traveled per unit time. When a moving object changes direction, its velocity changes even though its speed may not have changed. Confusing the scientific definition of *velocity* with its everyday meaning will prevent a correct understanding of some of the basic laws of physics and will lead to incorrect answers.

Mass, as used in everyday language, has several different meanings. Sometimes *mass* and *weight* are used interchangeably. In physics, mass and weight are *not* interchangeable. Mass is a measure of inertia—the tendency of an object at rest to remain at rest or, if moving, to continue moving with the same velocity. Weight, on the other hand, is a measure of the gravitational pull on an object.

There are two important reasons for the way in which we define physical quantities. First, physics is an experimental science. The results of an experiment must be stated unambiguously so that other scientists can perform similar experiments and compare their results. Quantities must be defined precisely to enable experimental measurements to be uniform no matter where they are made. Second, physics is a mathematical science. We use mathematics to quantify the relationships among physical quantities. These relationships can be expressed mathematically only if the quantities being investigated have precise definitions.

1.3 THE USE OF MATHEMATICS

A working knowledge of algebra, trigonometry, and geometry is essential to the study of introductory physics. Some of the more important mathematical tools are reviewed in Appendix A. If you know that your mathematics background is shaky, you might want to test your mastery by doing some problems from a math textbook. You may find it useful to try the ALEKS® *Math Prep for College Physics* online course, available at www.aleks.com/highered/math.

Algebraic symbols in equations stand for quantities that consist of numbers *and units.* The number represents a measurement and the measurement is made in terms of some standard; the unit indicates what standard is used. In physics, using a number to specify a quantity is meaningless unless we also specify the unit of measurement. When buying silk to make a sari, do we need a length of 5 millimeters, 5 meters, or 5 kilometers? Is the term paper due in 3 minutes, 3 days, or 3 weeks? Systems of units and unit conversions are discussed in Section 1.5.

There are not enough letters in the alphabet to assign a unique letter to each quantity. The same letter V can represent volume in one context and voltage in another. Avoid attempting to solve problems by picking equations that seem to have the correct letters. A skilled problem-solver understands *specifically* what quantity each symbol in a particular equation represents, can specify correct units for each quantity, and understands the situations to which the equation applies.

"Factors," Proportions, and Ratios In the language of physics, the word *factor* is used frequently, often in a rather idiosyncratic way. If the power emitted by a radio transmitter has doubled, we might say that the power has "increased by a factor of 2." If the concentration of sodium ions in the bloodstream is half of what it was previously, we might say that the concentration has "decreased by a factor of 2," or, in a blatantly inconsistent way, someone else might say that it has "decreased by a factor of $\frac{1}{2}$." The *factor* is the number by which a quantity is multiplied or divided when it is changed from one value to another. In other words, the factor is really a ratio. In the case of the radio transmitter, if P_0 represents the initial power and P represents the power after new equipment is installed, we write

$$\frac{P}{P_0} = 2$$

It is also common to talk about "increasing 5%" or "decreasing 20%." If a quantity increases $n\%$, that is the same as saying that it is multiplied by a factor of $1 + (n/100)$. If a quantity decreases $n\%$, then it is multiplied by a factor of $1 - (n/100)$. For example, an increase of 5% means 1.05 times the original value, and a decrease of 4% means it is 0.96 times the original value. (See Percentages in Appendix A.5.)

Physicists talk about increasing "by some factor" because it often simplifies a problem to think in terms of *proportions*. When we say that A is proportional to B (written $A \propto B$), we mean that if B increases by some factor, then A must increase by the same factor. In other words, the ratio of two values of B is equal to the ratio of the corresponding values of A: $B_2/B_1 = A_2/A_1$. For instance, the circumference of a circle equals 2π times the radius: $C = 2\pi r$. Therefore $C \propto r$. If the radius doubles, the circumference also doubles. The area of a circle is proportional to the *square* of the radius ($A = \pi r^2$, so $A \propto r^2$). The area must increase by the same factor as the radius *squared*, so if the radius doubles, the area increases by a factor of $2^2 = 4$. Written as a proportion, $A_2/A_1 = (r_2/r_1)^2 = 2^2 = 4$. See Appendix A.5 for more information about ratios and proportions.

Example 1.1

Osteoporosis

Severe osteoporosis can cause the density of bone to decrease as much as 40% (Fig. 1.2). What is the bone density of this degraded bone if the density of healthy bone is 1.5 g/cm^3?

Strategy A decrease of n% means the quantity is multiplied by $1 - (n/100)$.

Solution $1.5\ \text{g/cm}^3 \times [1 - (40/100)] = 1.5\ \text{g/cm}^3 \times 0.60 = 0.90\ \text{g/cm}^3$

Discussion Quick check: The final density is a bit more than half the original density, as expected for a 40% decrease.

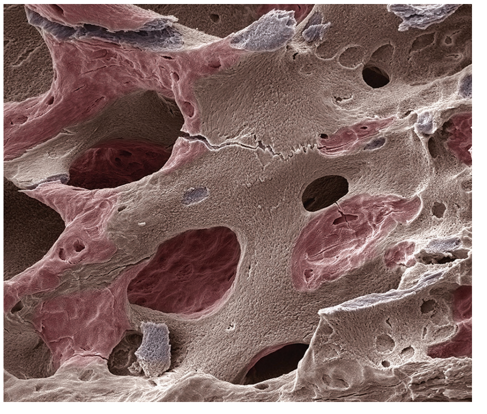

Figure 1.2

Colorized scanning electron micrograph of the porous structure inside an osteoporotic bone. Osteoporosis causes a reduction in bone density and an increase in porosity, resulting in increased brittleness and a greater risk of fracture. It is a common cause of fracture among the elderly.

Practice Problem 1.1 Red Blood Cell Count

A hospital patient's red blood count (RBC) is 5.0×10^6 cells per microliter ($5.0 \times 10^6\ \mu\text{L}^{-1}$) on Tuesday; on Wednesday it is $4.8 \times 10^6\ \mu\text{L}^{-1}$. What is the percentage change in the RBC?

Example 1.2

Effect of Increasing Radius on the Volume of a Sphere

The volume of a sphere is given by the equation

$$V = \frac{4}{3}\pi r^3$$

where V is the volume and r is the radius of the sphere. If a basketball has a radius of 12.4 cm and a tennis ball has a radius of 3.20 cm, by what factor is the volume of the basketball larger than the volume of the tennis ball?

Strategy The problem gives the values of the radii for the two balls. To keep track of which ball's radius and volume we mean, we use subscripts "b" for basketball and "t" for tennis ball. The radius of the basketball is r_b and the radius of the tennis ball is r_t. Since $\frac{4}{3}$ and π are constants, we can work in terms of proportions.

continued on next page

Example 1.2 continued

Solution The ratio of the basketball radius to that of the tennis ball is

$$\frac{r_b}{r_t} = \frac{12.4\text{ cm}}{3.20\text{ cm}} = 3.875$$

The volume of a sphere is proportional to the cube of its radius [Eq. (A-47)]:

$$V \propto r^3$$

Since the basketball radius is larger by a factor of 3.875, and volume is proportional to the cube of the radius, the new volume should be bigger by a factor of $3.875^3 \approx 58.2$.

Discussion A slight variation on the solution is to write out the proportionality in terms of ratios of the corresponding sides of the two equations (Section A.5):

$$\frac{V_b}{V_t} = \frac{\frac{4}{3}\pi r_b^3}{\frac{4}{3}\pi r_t^3} = \left(\frac{r_b}{r_t}\right)^3$$

Substituting the ratio of r_b to r_t yields

$$\frac{V_b}{V_t} = 3.1875^3 \approx 58.2$$

which says that V_b is approximately 58.2 times V_t.

Practice Problem 1.2 Power Dissipated by a Lightbulb

The electrical power P dissipated by a lightbulb of resistance R is $P = V^2/R$, where V represents the line voltage. During a brownout, the line voltage is 10.0% less than its normal value. How much power is drawn by a lightbulb during the brownout if it normally draws 60.0 W (watts)? Assume that the resistance does not change.

CHECKPOINT 1.3

If the radius of the sphere is increased by a factor of 3, by what factor does the volume of the sphere change?

1.4 SCIENTIFIC NOTATION AND SIGNIFICANT FIGURES

In physics, we deal with some numbers that are very small and others that are very large. It can get cumbersome to write numbers in conventional decimal notation. In **scientific notation**, any number is written as a number between 1 and 10 times an integer power of ten. Thus the radius of Earth, approximately 6 380 000 m at the equator, can be written 6.38×10^6 m; the radius of a hydrogen atom, 0.000 000 000 053 m, can be written 5.3×10^{-11} m. Scientific notation eliminates the need to write zeros to locate the decimal point correctly. Tip: Learn how to use the button on your calculator (usually labeled EE) to enter a number in scientific notation. To enter 1.2×10^8, press 1.2, EE, 8. See Appendix A.4 for a review of how to do calculations involving exponents.

In science, a measurement or the result of a calculation must indicate the **precision** to which the number is known. The precision of a device used to measure something is limited by the finest division on the scale. Using a meterstick with millimeter divisions as the smallest separations, we can measure a length to a precise number of millimeters and we can estimate a fraction of a millimeter between two divisions. If the meterstick has centimeter divisions as the smallest separations, we measure a precise number of centimeters and estimate the fraction of a centimeter that remains.

Significant Figures The most basic way to indicate the precision of a quantity is to write it with the correct number of **significant figures**. The significant figures are all the digits that are known accurately plus the one estimated digit. If we say that the distance from here to the state line is 12 km, that does not mean we know the distance to be *exactly*

12 km. Rather, the distance is 12 km *to the nearest kilometer*. If instead we said that the distance is 12.0 km, that would indicate that we know the distance to the nearest *tenth* of a kilometer. More significant figures indicate a greater degree of precision.

Rules for Identifying Significant Figures

1. Nonzero digits are always significant.
2. Final or ending zeros written to the right of the decimal point are significant.
3. Zeros written to the right of the decimal point for the purpose of spacing the decimal point are not significant.
4. Zeros written to the left of the decimal point may be significant, or they may only be there to space the decimal point. For example, 200 cm could have one, two, or three significant figures; it's not clear whether the distance was measured to the nearest 1 cm, to the nearest 10 cm, or to the nearest 100 cm. On the other hand, 200.0 cm has four significant figures (see rule 5). Rewriting the number in scientific notation is one way to remove the ambiguity. In this book, when a number has zeros to the left of the decimal point, you may *assume a minimum of two significant figures.*
5. Zeros written between significant figures are significant.

Example 1.3

Identifying the Number of Significant Figures

For each of these values, identify the number of significant figures and rewrite it in standard scientific notation.

(a) 409.8 s
(b) 0.058 700 cm
(c) 9500 g
(d) 950.0×10^1 mL

Strategy We follow the rules for identifying significant figures as given. To rewrite a number in scientific notation, we move the decimal point so that the number to the left of the decimal point is between 1 and 10 and compensate by multiplying by the appropriate power of ten.

Solution (a) All four digits in 409.8 s are significant. The zero is between two significant figures, so it is significant. To write the number in scientific notation, we move the decimal point two places to the left and compensate by multiplying by 10^2: 4.098×10^2 s.

(b) The first two zeros in 0.058 700 cm are not significant; they are used to place the decimal point. The digits 5, 8, and 7 are significant, as are the two final zeros. The answer has five significant figures: 5.8700×10^{-2} cm.

(c) The 9 and 5 in 9500 g are significant, but the zeros are ambiguous. This number could have two, three, or four significant figures. If we take the most cautious approach and assume the zeros are not significant, then the number in scientific notation is 9.5×10^3 g.

(d) The final zero in 950.0×10^1 mL is significant since it comes after the decimal point. The zero to its left is also significant since it comes between two other significant digits. The result has four significant figures. The number is not in *standard* scientific notation since 950.0 is not between 1 and 10; in scientific notation we write 9.500×10^3 mL.

Discussion Scientific notation clearly indicates the number of significant figures since all zeros are significant; none are used only to place the decimal point. In (c), if the measurement was made to the nearest gram, we would write 9.500×10^3 g to show that the zeros are significant.

Practice Problem 1.3 Identifying Significant Figures

State the number of significant figures in each of these measurements and rewrite them in standard scientific notation.

(a) 0.000 105 44 kg (b) 0.005 800 cm (c) 602 000 s

Significant Figures in Calculations

1. When two or more quantities are added or subtracted, the result is as precise as the *least precise* of the quantities (Example 1.4). If the quantities are written in scientific notation with different powers of ten, first rewrite them with the same power of ten. After adding or subtracting, round the result, keeping only as many decimal places as are significant in *all* of the quantities that were added or subtracted.
2. When quantities are multiplied or divided, the result has the same number of significant figures as the quantity with the *smallest number of significant figures* (see Example 1.5).
3. In a series of calculations, rounding to the correct number of significant figures should be done only at the end, *not at each step*. Rounding at each step would increase the chance that roundoff error could snowball and adversely affect the accuracy of the final answer. It's a good idea to keep *at least two* extra significant figures in calculations, then round at the end.

Example 1.4

Significant Figures in Addition

Calculate the sum 44.560 05 s + 0.0698 s + 1103.2 s.

Strategy The sum cannot be more precise than the least precise of the three quantities. The quantity 44.560 05 s is known to the nearest 0.000 01 s, 0.0698 s is known to the nearest 0.0001 s, and 1103.2 s is known to the nearest 0.1 s. Therefore the least precise is 1103.2 s. The sum has the same precision; it is known to the nearest tenth of a second.

Solution According to the calculator,

$$44.560\ 05 + 0.0698 + 1103.2 = 1147.829\ 85$$

We do *not* want to write all of those digits in the answer. That would imply greater precision than we actually have. Rounding to the nearest tenth of a second, the sum is written

$$= 1147.8 \text{ s}$$

which has five significant figures.

Discussion Note that the least precise measurement is not necessarily the one with the fewest number of significant figures. The least precise is the one whose rightmost significant figure represents the largest unit: the "2" in 1103.2 s represents 2 tenths of a second. In addition or subtraction, we are concerned with the precision rather than the number of significant figures. The three quantities to be added have seven, three, and five significant figures, respectively, but the sum has five significant figures.

Practice Problem 1.4 Significant Figures in Subtraction

Calculate the difference 568.42 m − 3.924 m and write the result in scientific notation. How many significant figures are in the result?

Example 1.5

Significant Figures in Multiplication

Find the product of 45.26 m/s and 2.41 s. How many significant figures does the product have?

Strategy The product should have the same number of significant figures as the factor with the least number of significant figures.

Solution A calculator gives

$$45.26 \times 2.41 = 109.0766$$

Since the answer should have only three significant figures, we round the answer to

$$45.26 \text{ m/s} \times 2.41 \text{ s} = 109 \text{ m}$$

continued on next page

Example 1.5 continued

Discussion Writing the answer as 109.0766 m would give the false impression that we know the answer to a precision of about 0.0001 m, whereas we actually have a precision of only about 1 m.

Note that although both factors were known to two decimal places, our solution is properly given with no decimal places. It is the number of significant figures that matters in multiplication or division. In scientific notation, we write 1.09×10^2 m.

Practice Problem 1.5 Significant Figures in Division

Write the solution to 28.84 m divided by 6.2 s with the correct number of significant figures.

When an integer, or a fraction of integers, is used in an equation, the precision of the result is not affected by the integer or the fraction; the number of significant figures is limited only by the measured values in the problem. The fraction $\frac{1}{2}$ in an equation is *exact;* it does not reduce the number of significant figures to one. In an equation such as $C = 2\pi r$ for the circumference of a circle of radius r, the factors 2 and π are exact. We use as many digits for π as we need to maintain the precision of the other quantities.

Order-of-Magnitude Estimates Sometimes a problem may be too complicated to solve precisely, or information may be missing that would be necessary for a precise calculation. In such a case, an **order-of-magnitude** solution is the best we can do. By *order of magnitude,* we mean "roughly what power of ten?" (see Fig. 1.3). An order of magnitude calculation is done to at most one significant figure. Even when a more precise solution is feasible, it is often a good idea to start with a quick, "**back-of-the-envelope estimate**" (a calculation so short that it could easily fit on the back

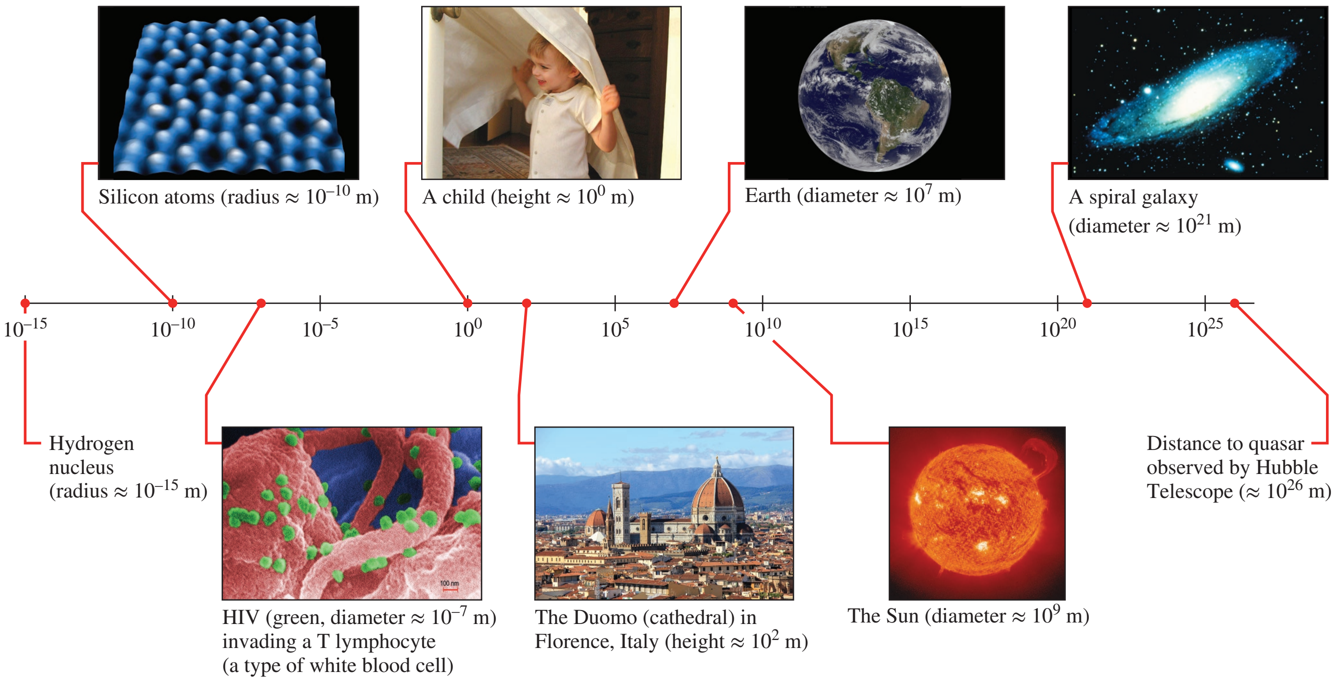

Figure 1.3 A few objects arranged according to the order of magnitude of their sizes. Note that the scale is logarithmic; moving to the right from one tic to the next increases the size by a *factor* of 100 000. From the size of the hydrogen nucleus to the distance to a quasar, these distances span 41 orders of magnitude.

©Andrew Dunn/Alamy; ©Jennifer Merlis; Source: NASA; ©Imaging nature/Getty Images; ©CDC/C. Goldsmith, P. Feorino, E. L. Palmer, W. R. McManus; ©Moment Open/Thomas Janisch/Getty Images; ©Digital Vision/Getty Image of an envelope). Why? Because we can often make a good guess about the correct order of magnitude of the answer to a problem, even before we start solving the problem. If the answer comes out with a different order of magnitude, we go back and search for an error. Suppose a problem concerns a vase that is knocked off a fourth-story window ledge. We can guess by experience the order of magnitude of the time it takes the vase to hit the ground. It might be 1 s, or 2 s, but we are certain that it is *not* 1000 s or 0.00001 s.

CHECKPOINT 1.4

What are some of the reasons for making order-of-magnitude estimates?

1.5 UNITS

A **metric system** of units has been used for many years in scientific work and in European countries. The metric system is based on powers of ten. In 1960, the General Conference of Weights and Measures, an international authority on units, proposed a revised metric system called the *Système International d'Unités* in French (abbreviated **SI**), which uses the meter (m) for length, the kilogram (kg) for mass, the second (s) for time, and four more base units (Table 1.1). **Derived units** are constructed from combinations of the base units. For example, the SI unit of force is $kg \cdot m/s^2$ (which can also be written $kg \cdot m \cdot s^{-2}$); this combination of units is given a special name, the newton (N), in honor of Isaac Newton. When units are named after famous scientists, the name of the unit is written with a lowercase letter, even though it is based on a proper name; the *symbol* for the unit is written with an uppercase letter. Appendix B has a complete listing of the derived SI units used in this book.

As an alternative to explicitly writing powers of ten, SI uses prefixes for units to indicate power of ten factors. Table 1.2 shows some of the powers of ten and the SI prefixes used for them. These are also listed in Appendix B. Note that when an SI

Table 1.1 SI Base Units

Quantity	Unit Name	Symbol	Present Definition (2017)*
Length	meter	m	The distance traveled by light in vacuum during a time interval of 1/299 792 458 s.
Mass	kilogram	kg	The mass of the international prototype of the kilogram.
Time	second	s	The duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.
Electric current	ampere	A	The constant current in two long, thin, straight, parallel conductors placed 1 m apart in vacuum that would produce a force on the conductors of 2×10^{-7} newtons per meter of length.
Temperature	kelvin	K	The fraction 1/273.16 of the thermodynamic temperature of the triple point of water.
Amount of substance	mole	mol	The amount of substance that contains as many elementary entities as there are atoms in 0.012 kg of carbon-12.
Luminous intensity	candela[†]	cd	The luminous intensity, in a given direction, of a source that emits radiation of frequency 540×10^{12} Hz and that has a radiant intensity in that direction of 1/683 watts per steradian.

*New definitions of the SI base units are expected to be finalized in 2018.
[†]Not used in this book