Conversion Factors

Length

1 in = 2.54 cm
1 cm = 0.394 in
1 ft = 30.5 cm
1 m = 39.4 in = 3.281 ft
1 km = 0.621 mi
1 mi = 5,280 ft = 1.609 km
1 light-year = 9.461×10^{15} m

Mass

1 lb = 453.6 g (where $g = 9.8$ m/s^2)
1 kg = 2.205 lb (where $g = 9.8$ m/s^2)
1 atomic mass unit u = 1.66061×10^{-27} kg

Volume

1 liter = 1.057 quarts
1 in^3 = 16.39 cm^3
1 gallon = 3.786 liter
1 ft^3 = 0.02832 m^3

Energy

1 cal = 4.184 J
1 J = 0.738 ft·lb = 0.239 cal
1 ft·lb = 1.356 J
1 Btu = 252 cal = 778 ft·lb
1 kWh = 3.60×10^6 J = 860 kcal
1 hp = 550 ft·lb/s = 746 W
1 W = 0.738 ft·lb/s
1 Btu/h = 0.293 W
Absolute zero (0K) = −273.15°C
1 J = 6.24×10^{18} eV
1 eV = 1.6022×10^{-19} J

Speed

1 km/h = 0.2778 m/s = 0.6214 mi/h
1 m/s = 3.60 km/h = 2.237 mi/h = 3.281 ft/s
1 mi/h = 1.61 km/h = 0.447 m/s = 1.47 ft/s
1 ft/s = 0.3048 m/s = 0.6818 mi/h

Force

1 N = 0.2248 lb
1 lb = 4.448 N

Pressure

1 atm = 1.013 bar = 1.013×10^5 N/m^2 = 14.7 lb/in^2
1 lb/in^2 = 6.90×10^3 N/m^2

Metric Prefixes

Prefix	Symbol	Meaning	Unit Multiplier
exa-	E	quintillion	10^{18}
peta-	P	quadrillion	10^{15}
tera-	T	trillion	10^{12}
giga-	G	billion	10^{9}
mega-	M	million	10^{6}
kilo-	k	thousand	10^{3}
hecto-	h	hundred	10^{2}
deka-	da	ten	10^{1}
unit			
deci-	d	one-tenth	10^{-1}
centi-	c	one-hundredth	10^{-2}
milli-	m	one-thousandth	10^{-3}
micro-	μ	one-millionth	10^{-6}
nano-	n	one-billionth	10^{-9}
pico-	p	one-trillionth	10^{-12}
femto-	f	one-quadrillionth	10^{-15}
atto-	a	one-quintillionth	10^{-18}

Physical Constants

Quantity	Approximate Value
Gravity (Earth)	$g = 9.8$ m/s^2
Gravitational law constant	G = 6.67×10^{-11} N·m^2/kg^2
Earth radius (mean)	6.38×10^6 m
Earth mass	5.97×10^{24} kg
Earth-Sun distance (mean)	1.50×10^{11} m
Earth-Moon distance (mean)	3.84×10^8 m
Fundamental charge	1.60×10^{-19} C
Coulomb law constant	$k = 9.00 \times 10^9$ N·m^2/C^2
Electron rest mass	9.11×10^{-31} kg
Proton rest mass	1.6726×10^{-27} kg
Neutron rest mass	1.6750×10^{-27} kg
Bohr radius	5.29×10^{-11} m
Avogadro's number	6.022045×10^{23}/mol
Planck's constant	6.62×10^{-34} J·s
Speed of light (vacuum)	3.00×10^8 m/s
Pi	$\pi = 3.1415926536$

Greek Letters

Alpha	Α	α	Nu	Ν	ν
Beta	Β	β	Xi	Ξ	ξ
Gamma	Γ	γ	Omicron	Ο	ο
Delta	Δ	δ	Pi	Π	π
Epsilon	Ε	ε	Rho	Ρ	ρ
Zeta	Ζ	ζ	Sigma	Σ	σ
Eta	Η	η	Tau	Τ	τ
Theta	Θ	θ	Upsilon	Υ	υ
Iota	Ι	ι	Phi	Φ	φ
Kappa	Κ	κ	Chi	Χ	χ
Lambda	Λ	λ	Psi	Ψ	ψ
Mu	Μ	μ	Omega	Ω	ω

THIRTEENTH EDITION

PHYSICAL SCIENCE

BILL W. TILLERY
ARIZONA STATE UNIVERSITY

STEPHANIE J. SLATER
CENTER FOR ASTRONOMY & PHYSICS EDUCATION RESEARCH

TIMOTHY F. SLATER
UNIVERSITY OF WYOMING

McGraw Hill

PHYSICAL SCIENCE, THIRTEENTH EDITION

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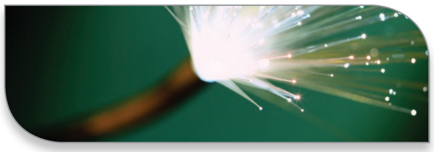
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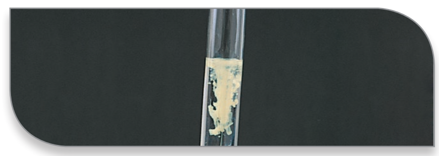
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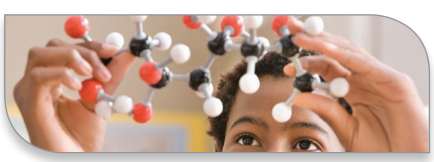

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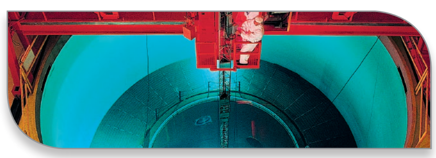

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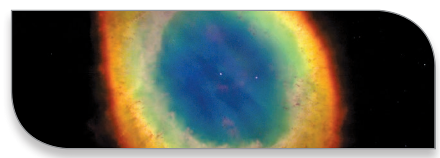

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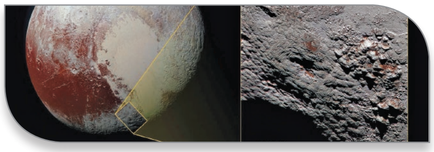

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Dr. Parvinder Sethi

PREFACE

Physical Science is a straightforward, easy-to-read but substantial introduction to the fundamental behavior of matter and energy. It is intended to serve the needs of nonscience majors who are required to complete one or more physical science courses. It introduces basic concepts and key ideas while providing opportunities for students to learn reasoning skills and a new way of thinking about their environment. No prior work in science is assumed. The language, as well as the mathematics, is as simple as can be practical for a college-level science course.

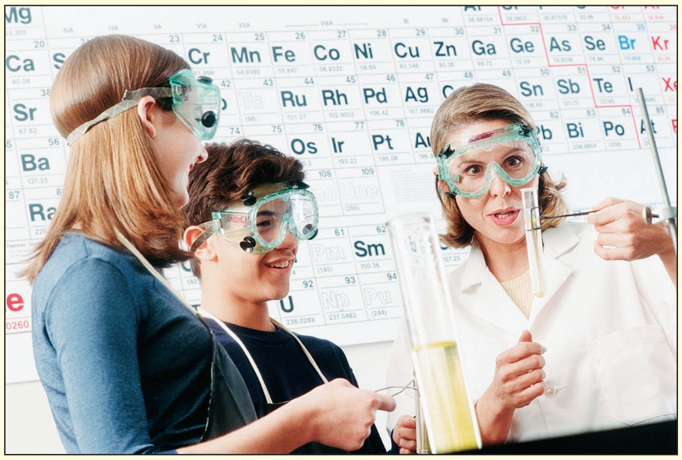
ORGANIZATION

The *Physical Science* sequence of chapters is flexible, and the instructor can determine topic sequence and depth of coverage as needed. The materials are also designed to support a conceptual approach or a combined conceptual and problem-solving approach. With laboratory studies, the text contains enough material for the instructor to select a sequence for a two-semester course. It can also serve as a text in a one-semester astronomy and earth science course or in other combinations.

MEETING STUDENT NEEDS

Physical Science is based on two fundamental assumptions arrived at as the result of years of experience and observation from teaching the course: (1) that students taking the course often have very limited background and/or aptitude in the natural sciences; and (2) that these types of student will better grasp the ideas and principles of physical science that are discussed with minimal use of technical terminology and detail. In addition, it is critical for the student to see relevant applications of the material to everyday life. Most of these everyday-life applications, such as environmental concerns, are not isolated in an arbitrary chapter; they are discussed where they occur naturally throughout the text.

Each chapter presents historical background where appropriate, uses everyday examples in developing concepts, and follows a logical flow of presentation. The historical chronology, of special interest to the humanistically inclined nonscience major, serves to humanize the science being presented. The use of everyday examples appeals to the nonscience major, typically accustomed to reading narration, not scientific technical writing, and also tends to bring relevancy to the material being presented. The logical flow of presentation is helpful to students not accustomed to thinking about relationships between what is being read and previous knowledge learned, a useful



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skill in understanding the physical sciences. Worked examples help students to integrate concepts and understand the use of relationships called equations. These examples also serve as a model for problem solving; consequently, special attention is given to *complete* unit work and to the clear, fully expressed use of mathematics. Where appropriate, chapters contain one or more activities, called *Concepts Applied,* that use everyday materials rather than specialized laboratory equipment. These activities are intended to bring the science concepts closer to the world of the student. The activities are supplemental and can be done as optional student activities or as demonstrations.

A STUDENT-FOCUSED REVISION

For the thirteenth edition, real student data points and input, derived from thousands of our LearnSmart users, were used to guide the revision. LearnSmart Heat Maps provided a quick visual snapshot of usage of portions of the text and the relative difficulty students experienced in mastering the content. With these data, the text content was honed:

- If the data indicated that the subject covered was more difficult than other parts of the book, as evidenced by a high proportion of students responding incorrectly to LearnSmart probes, the text content was substantively revised or reorganized to be as clear and illustrative as possible.
- When the data showed that a smaller percentage of the students had difficulty learning the material, the text was revised to provide a clearer presentation by rewriting the section or providing additional example problems to strengthen student problem-solving skills.

This process was used to direct the revision of this new edition, along with other instructor and student feedback. The following “New to This Edition” summary lists the more major additions and refinements.

NEW TO THIS EDITION

Numerous revisions have been made to the text to update the content on current events and to make the text even more user-friendly and relevant for students.

The list below provides chapter-specific updates:

- Throughout the text, issues and illustrations surrounding science, technology and society have been significantly updated, replacing descriptions of out-of-date technologies and replacing them with newer, more relevant ones.
- Photographs and illustrations have received a major face-lift. More than 20 new photographs and illustrations have been included.
- All chapters have been revised to increase readability of the text, figure and illustrations.
- The revised Chapter 3 includes completely revised presentation on energy and the environment, incorporating new worldwide datasets.
- Chapter 23 includes the most recent IPCC information on Earth’s changing climate and its causes.

THE LEARNING SYSTEM

Physical Science has an effective combination of innovative learning aids intended to make the student’s study of science more effective and enjoyable. This variety of aids is included to help students clearly understand the concepts and principles that serve as the foundation of the physical sciences.

OVERVIEW

Chapter 1 provides an *overview* or orientation to what the study of physical science in general and this text in particular are all about. It discusses the fundamental methods and techniques used by scientists to study and understand the world around us. It also explains the problem-solving approach used throughout the text so that students can more effectively apply what they have learned.

CHAPTER OPENING TOOLS

Core Concept and Supporting Concepts

Core and supporting concepts integrate the chapter concepts and the chapter outline. The core and supporting concepts outline and emphasize the concepts at a chapter level. The concepts list is designed to help students focus their studies by identifying the most important topics in the chapter outline.

Chapter Outline

The chapter outline includes all the major topic headings and subheadings within the body of the chapter. It gives you a quick glimpse of the chapter’s contents and helps you locate sections dealing with particular topics.

Chapter Overview

Each chapter begins with an introductory overview. The overview previews the chapter’s contents and what you can expect to learn from reading the chapter. It adds to the general outline of the chapter by introducing you to the concepts to be covered, facilitating the integration of topics, and helping you to stay focused and organized while reading the chapter for the first time. After you read the introduction, browse through the chapter, paying particular attention to the topic headings and illustrations so that you get a feel for the kinds of ideas included within the chapter.

EXAMPLES

Each topic discussed within the chapter contains 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 the physical sciences.

APPLYING SCIENCE TO THE REAL WORLD

Concepts Applied

Each chapter also includes one or more *Concepts Applied* boxes. These activities are simple investigative exercises that students can perform at home or in the classroom to demonstrate important concepts and reinforce understanding of them. This feature also describes the application of those concepts to everyday life.

Closer Look

One or more boxed *Closer Look* features can be found in each chapter of *Physical Science*. These readings present topics of special human or environmental concern (the use of seat belts, acid rain, and air pollution, for example). In addition to environmental concerns, topics are presented on interesting technological applications (passive solar homes, solar cells, catalytic converters, etc.) or on the cutting edge of scientific research (for example, El Niño and dark energy). All boxed features are informative materials that are supplementary in nature. The *Closer Look* readings serve to underscore the relevance of physical science in confronting the many issues we face daily.

Science Sketches

This feature found in each chapter of the 12th edition text, engages students in creating their own explanations and analogies by challenging them to create visual representations of concepts.

Science and Society

These readings relate the chapter’s content to current societal issues. Many of these boxes also include Questions to Discuss that provide an opportunity to discuss issues with your peers.

Myths, Mistakes, and Misunderstandings

These brief boxes provide short, scientific explanations to dispel a societal myth or a home experiment or project that enables you to dispel the myth on your own.

END-OF-CHAPTER FEATURES

At the end of each chapter, students will find the following materials:

- *Summary:* highlights the key elements of the chapter.
- *Summary of Equations:* reinforces retention of the equations presented.
- *Key Terms:* gives page references for finding the terms defined within the context of the chapter reading.
- *Applying the Concepts:* tests comprehension of the material covered with a multiple-choice quiz.
- *Questions for Thought:* challenges students to demonstrate their understanding of the topics.
- *Parallel Exercises:* reinforce problem-solving skills. There are two groups of parallel exercises, Group A and Group B. The Group A parallel exercises have complete solutions worked out, along with useful comments, in appendix E. The Group B parallel exercises are similar to those in Group A but do not contain answers in the text. By working through the Group A parallel exercises and checking the solutions in appendix E, students will gain confidence in tackling the parallel exercises in Group B and thus reinforce their problem-solving skills.
- *For Further Analysis:* includes exercises containing analysis or discussion questions, independent investigations, and activities intended to emphasize critical thinking skills and societal issues and to develop a deeper understanding of the chapter content.
- *Invitation to Inquiry:* includes exercises that consist of short, open-ended activities that allow you to apply investigative skills to the material in the chapter.

END-OF-TEXT MATERIALS

Appendices providing math review, additional background details, solubility and humidity charts, solutions for the in-chapter follow-up examples, and solutions for the Group A Parallel Exercises can be found at the back of the text. There is also a Glossary of all key terms, an index, and special tables printed on the inside covers for reference use.

SUPPLEMENTARY MATERIAL

Presentation Tools

Complete set of electronic book images and assets for instructors.

Build instructional materials wherever, whenever, and however you want!

Accessed from your textbook's Connect Instructor's Resources, **Presentation Tools** is an online collection of photos, artwork, and animations that can be used to create customized lectures, visually enhanced tests and quizzes, compelling course websites, or attractive printed support materials. All assets are copyrighted by McGraw Hill Higher Education but can be used by instructors for classroom purposes. The visual resources in this collection include:

- **Art and Photo Library:** Full-color digital files of all of the illustrations and many of the photos in the text can be readily incorporated into lecture presentations, exams, or custom-made classroom materials.
- **Worked Example Library, Table Library, and Numbered Equations Library:** Access the worked examples, tables, and equations from the text in electronic format for inclusion in your classroom resources.
- **Animations Library:** Files of animations and videos covering the many topics in *Physical Science* are included so that you can easily make use of these animations in a lecture or classroom setting.

Also residing on your textbook's website are

- **PowerPoint Slides:** For instructors who prefer to create their lectures from scratch, all illustrations, photos, and tables are preinserted by chapter into blank PowerPoint slides.
- **Lecture Outlines:** Lecture notes, incorporating illustrations, examples, and tables, have been written to the thirteenth edition text. They are provided in PowerPoint format so that you may use these lectures as written or customize them to fit your lecture.

Laboratory Manual

The *laboratory manual,* written and classroom tested by the author, presents a selection of laboratory exercises specifically written for the interests and abilities of nonscience majors. There are laboratory exercises that require measurement, data analysis, and thinking in a more structured learning environment, while alternative exercises that are open-ended "Invitations to Inquiry" are provided for instructors who would like a less structured approach. When the laboratory manual is used with *Physical Science,* students will have an opportunity to master basic scientific principles and concepts, learn new problem-solving and thinking skills, and understand the nature of scientific inquiry from the perspective of hands-on experiences. The *instructor's edition of the laboratory manual* can be found on the *Physical Science* Connect Instructor's Resources.

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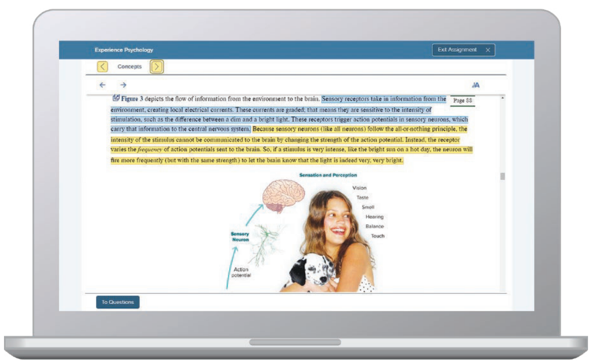
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>
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Timothy F. Slater, *University of Wyoming*
Gina Seegers Szablewski, *University of Wisconsin - Milwaukee*

The authors of the text, Stephanie and Timothy Slater, revised the PowerPoint Lecture Outlines, the Instructor's Manual, and the Test Bank for the thirteenth edition.

MEET THE AUTHORS

BILL W. TILLERY

Bill W. Tillery is professor emeritus of Physics at Arizona State University, where he was a member of the faculty from 1973 to 2006. He earned a bachelor's degree at Northeastern State University and master's and doctorate degrees from the University of Northern Colorado. Before moving to Arizona State University, he served as director of the Science and Mathematics Teaching Center at the University of Wyoming and as an assistant professor at Florida State University. Bill served on numerous councils, boards, and committees, and he was honored as the "Outstanding University Educator" at the University of Wyoming. He was elected the "Outstanding Teacher" in the Department of Physics and Astronomy at Arizona State University.

During his time at Arizona State, Bill taught a variety of courses, including general education courses in science and society, physical science, and introduction to physics. He received more than forty grants from the National Science Foundation, the U.S. Office of Education, private industry (Arizona Public Service), and private foundations (The Flinn Foundation) for science curriculum development and science teacher in-service training. In addition to teaching and grant work, Bill authored or coauthored more than sixty textbooks and many monographs and served as editor of three separate newsletters and journals.

STEPHANIE J. SLATER

Stephanie Slater is the Director of the CAPER Center for Astronomy & Physics Education Research. After undergraduate studies at Massachusetts Institute of Technology and graduate work at Montana State University, Dr. Slater earned her Ph.D. from the University of Arizona in the Department of Teaching, Learning and Sociocultural Studies studying how undergraduate research experiences influence the professional career pathways of women scientists. Dr. Slater was selected as the American Physical Society's Woman Physicist of the Month in December 2013 and received both NASA Top Star and NASA Gold Star Education awards.

With more than twenty years of teaching experience, Dr. Slater has written science textbooks for undergraduate classes and books on education research design and methods for graduate courses. Her work on educational innovations has been funded by the National Science Foundation and NASA and she has served on numerous science education and outreach committees for the American Association of Physics Teachers, the American Physical Society, the American Geophysical Union, and the American Institute of Physics, among others. She is also a frequent lecturer at science fiction conventions, illustrating how science fiction books, television series, and movies describe how humans interact at the intersection of science and culture.

TIMOTHY F. SLATER

Tim Slater has been the University of Wyoming Excellence in Higher Education Endowed Professor of Science Education since 2008. Prior to joining the faculty at the University of Wyoming, he was an astronomer at the University of Arizona from 2001 to 2008 where he was the first professor in the United States to earn tenure in a top-ranked Astronomy Department on the basis of his scholarly publication and grant award record in astronomy education research. From 1996 to 2001, he was a research professor of physics at Montana State University.

Dr. Slater earned a Ph.D. at the University of South Carolina, an MS at Clemson University, and two Bachelor's degrees at Kansas State University. He is widely known as the "professor's professor" because of the hundreds of college teaching talks and workshops he has given to thousands of professors on innovative teaching methods. Dr. Slater serves as the Editor-in-Chief of the *Journal of Astronomy & Earth Sciences Education* and was the initial U.S. Chairman of the International Year of Astronomy. An avid motorcycle rider, he is the author of twenty-six books, has written more than one hundred peer-reviewed journal articles cited thousands of times, and been the recipient of numerous teaching awards.

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- access all test bank content from a particular title.
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- pin questions to a specific location within a test.
- determine your preferred treatment of algorithmic questions.
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1

What Is Science?

Physical science is concerned with your physical surroundings and your concepts and understanding of these surroundings.
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CORE CONCEPT

Science is a way of thinking about and understanding your environment.

OUTLINE

Objects and Properties
Properties are qualities or attributes that can be used to describe an object or event.

Data
Data is measurement information that can be used to describe objects, conditions, events, or changes.

Scientific Method
Science investigations include collecting observations, developing explanations, and testing explanations.

Laws and Principles
Scientific laws describe relationships between events that happen time after time, describing *what* happens in nature.

Quantifying Properties
Measurement is used to accurately describe properties of objects or events.

Symbols and Equations
An equation is a statement of a relationship between variables.

Models and Theories
A scientific theory is a broad working hypothesis based on extensive experimental evidence, describing *why* something happens in nature.

OVERVIEW

Have you ever thought about your thinking and what you know? On a very simplified level, you could say that everything you know came to you through your senses. You see, hear, and touch things of your choosing, and you can also smell and taste things in your surroundings. Information is gathered and sent to your brain by your sense organs. Somehow, your brain processes all this information in an attempt to find order and make sense of it all. Finding order helps you understand the world and what may be happening at a particular place and time. Finding order also helps you predict what may happen next, which can be very important in a lot of situations.

This is a book on thinking about and understanding your physical surroundings. These surroundings range from the obvious, such as the landscape (Figure 1.1) and the day-to-day weather, to the not so obvious, such as how atoms are put together. You will learn how to think about your surroundings, whatever your previous experience with thought-demanding situations. This first chapter is about "tools and rules" that you will use in the thinking process.

1.1 OBJECTS AND PROPERTIES

Physical science is concerned with making sense out of the physical environment. The early stages of this "search for sense" usually involve *objects* in the environment, things that can be seen or touched. These could be objects you see every day, such as a glass of water, a moving automobile, or a blowing flag. They could be quite large, such as the Sun, the Moon, or even the solar system, or invisible to the unaided human eye. Physical scientists are usually focused on studying nonliving things, leaving the domain of living things for life scientists.

As you were growing up, you learned to form a generalized mental image of objects called a *concept*. Your concept of an object is an idea of what it is, in general, or what it should be according to your idea. You usually have a word stored away in your mind that represents a concept. The word *chair*, for example, probably evokes an idea of "something to sit on." Your generalized mental image for the concept that goes with the word *chair* probably includes a four-legged object with a backrest. Upon close inspection, most of your (and everyone else's) concepts are found to be somewhat vague. For example, if the word *chair* brings forth a mental image of something with four legs and a backrest (the concept), what is the difference between a "high chair" and a "bar stool"? When is a chair a chair and not a stool (Figure 1.2)? These kinds of questions can be troublesome for many people.

Not all of your concepts are about material objects. You also have concepts about intangibles such as time, motion, and relationships between events. As was the case with concepts of material objects, words represent the existence of intangible concepts. For example, the words *second, hour, day,* and *month* represent concepts of time. A concept of the pushes and pulls that come with changes of motion during an airplane flight might be represented with such words as *accelerate* and *falling*. Intangible concepts might seem to be more abstract since they do not represent material objects.

FIGURE 1.1 Your physical surroundings include naturally occurring things in the landscape as well as things people have made.
John Giustina/Photodisc/Getty Images

FIGURE 1.2 What is your concept of a chair? Is this a picture of a chair or is it a stool? Most people have concepts, or ideas of what things in general should be, that are loosely defined. The concept of a chair is one example, and this is a picture of a swivel office chair with arms. Ingram Publishing

FIGURE 1.3 Could you describe this rock to another person over the telephone so that the other person would know *exactly* what you see? This is not likely with everyday language, which is full of implied comparisons, assumptions, and inaccurate descriptions. Bill W. Tillery

By the time you reach adulthood, you have literally thousands of words to represent thousands of concepts. But most, you would find on inspection, are somewhat ambiguous and not at all clear-cut. That is why you find it necessary to talk about certain concepts for a minute or two to see if the other person has the same "concept" for words as you do. That is why when one person says, "Boy, was it hot!" the other person may respond, "How hot was it?" The meaning of *hot* can be quite different for two people, especially if one is from Arizona and the other from Alaska!

The problem with words, concepts, and mental images can be illustrated by imagining a situation involving you and another person. Suppose that you have found a rock that you believe would make a great bookend. Suppose further that you are talking to the other person on the telephone, and you want to discuss the suitability of the rock as a bookend, but you do not know the name of the rock. If you knew the name, you would simply state that you found a "_____." Then you would probably discuss the rock for a minute or so to see if the other person really understood what you were talking about. But not knowing the name of the rock and wanting to communicate about the suitability of the object as a bookend, what would you do? You would probably describe the characteristics, or **properties,** of the rock. Properties are the qualities or attributes that, taken together, are usually peculiar to an object. Since you commonly determine properties with your senses (smell, sight, hearing, touch, and taste), you could say that the properties of an object are the effect the object has on your senses. For example, you might say that the rock is a "big, yellow, smooth rock with shiny gold cubes on one side." But consider the mental image that the other person on the telephone forms when you describe these properties. It is entirely possible that the other person is thinking of something very different from what you are describing (Figure 1.3)!

As you can see, the example of describing a proposed bookend by listing its properties in everyday language leaves much to be desired. The description does not really help the other person form an accurate mental image of the rock. One problem with the attempted communication is that the description of any property implies some kind of *referent.* The word **referent** means that you *refer to,* or think of, a given property in terms of another, more familiar object. Colors, for example, are sometimes stated with a referent. Examples are "sky blue," "grass green," or "lemon yellow." The referents for the colors blue, green, and yellow are, respectively, the sky, living grass, and a ripe lemon.

Referents for properties are not always as explicit as they are for colors, but a comparison is always implied. Since the comparison is implied, it often goes unspoken and leads to assumptions in communications. For example, when you stated that the rock was "big," you assumed that the other person knew that you did not mean as big as a house or even as big as a bicycle. You assumed that the other person knew that you meant that the rock was about as large as a book, perhaps a bit larger.

Another problem with the listed properties of the rock is the use of the word *smooth*. The other person would not know if you meant that the rock *looked* smooth or *felt* smooth. After all, some objects can look smooth and feel rough. Other objects can look rough and feel smooth. Thus, here is another assumption, and probably all of the properties lead to implied comparisons, assumptions, and a not-very-accurate communication. This is the nature of your everyday language and the nature of most attempts at communication.

1.2 QUANTIFYING PROPERTIES

Typical day-to-day communications are often vague and leave much to be assumed. A communication between two people, for example, could involve one person describing some person, object, or event to a second person. The description is made by using referents and comparisons that the second person may or may not have in mind. Thus, such attributes as "long" fingernails or "short" hair may have entirely different meanings to different people involved in a conversation. Assumptions and vagueness can be avoided by using **measurement** in a description. Measurement is a process of comparing a property to a well-defined and agreed-upon referent. The well-defined and agreed-upon referent is used as a standard called a **unit.** The measurement process involves three steps: (1) *comparing* the referent unit to the property being described, (2) following a *procedure,* or operation, that specifies how the comparison is made, and (3) *counting* how many standard units describe the property being considered.

The measurement process uses a defined referent unit, which is compared to a property being measured. The *value* of the property is determined by counting the number of referent units. The name of the unit implies the procedure that results in the number. A measurement statement always contains a *number* and *name* for the referent unit. The number answers the question "How much?" and the name answers the question "Of what?" Thus, a measurement always tells you "how much of what." You will find that using measurements will sharpen your communications. You will also find that using measurements is one of the first steps in understanding your physical environment.

1.3 MEASUREMENT SYSTEMS

Measurement is a process that brings precision to a description by specifying the "how much" and "of what" of a property in a particular situation. A number expresses the value of the property, and the name of a unit tells you what the referent is as well as implies the procedure for obtaining the number. Referent units must be defined and established, however, if others are to understand and reproduce a measurement. When standards are established, the referent unit is called a **standard unit** (Figure 1.4). The use of standard units makes it possible to communicate and duplicate measurements. Standard units are usually defined and established by governments and their agencies that are created for that purpose. In the United States, the agency concerned with measurement standards is the National Institute of Standards and Technology. In Canada, the Standards Council of Canada oversees the National Standard System.

There are two major *systems* of standard units in use today, the *English system* and the *metric system.* The metric system is used throughout the world except in the United States, where both systems are in use. The continued use of the English system in the United States presents problems in international trade, so there is pressure for a complete conversion to the metric system. More and more metric units are being used in everyday measurements, but a complete conversion will involve an enormous cost. Appendix A contains a method for converting from one system to the other easily. Consult this section if you need to convert from one metric unit to another metric unit or to convert from English to metric units or vice versa. Conversion factors are listed inside the front cover.

People have used referents to communicate about properties of things throughout human history. The ancient Greek civilization, for example, used units of *stadia* to communicate about distances and elevations. The *stadium* was a unit of length of the racetrack at the local stadium (*stadia* is the plural of *stadium*), based on a length of 125 paces. Later civilizations, such as the ancient Romans, adopted the stadia and other referent units from the ancient Greeks. Some of these same referent units were later adopted by the early English civilization, which eventually led to the **English system** of measurement. Some adopted units of the English system were originally based on parts of the human body, presumably because you always had these referents with you (Figure 1.5). The inch, for example,

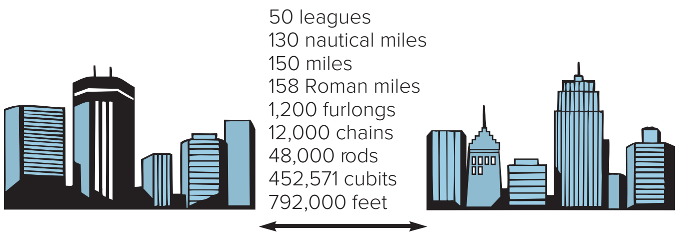


FIGURE 1.4 Which of the listed units should be used to describe the distance between these hypothetical towns? Is there an advantage to using any of the units? Any could be used, and when one particular unit is officially adopted, it becomes known as the *standard unit.*

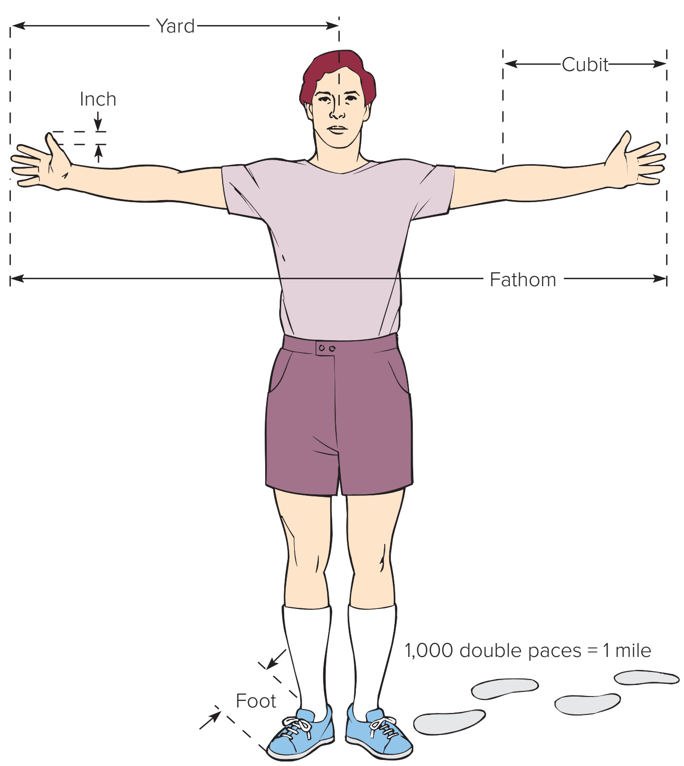


FIGURE 1.5 Many early units for measurement were originally based on the human body. Some of the units were later standardized by governments to become the basis of the English system of measurement.

TABLE 1.1

The SI Base Units

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

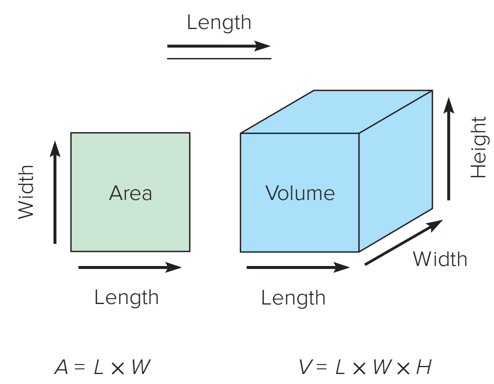


FIGURE 1.6 Area, or the extent of a surface, can be described by two length measurements. Volume, or the space that an object occupies, can be described by three length measurements. Length, however, can be described only in terms of how it is measured, so it is called a *fundamental property*.

used the end joint of the thumb for a referent. A foot, naturally, was the length of a foot, and a yard was the distance from the tip of the nose to the end of the fingers on an arm held straight out. A cubit was the distance from the end of an elbow to the fingertip, and a fathom was the distance between the fingertips of two arms held straight out. As you can imagine, there were problems with these early units because everyone had different-sized body parts. Beginning in the 1300s, the sizes of the various units were gradually standardized by English kings.

The **metric system** was established by the French Academy of Sciences in 1791. The academy created a measurement system that was based on invariable referents in nature, not human body parts. These referents have been redefined over time to make the standard units more reproducible. The *International System of Units,* abbreviated *SI,* is a modernized version of the metric system. Today, the SI system has seven base units that define standards for the properties of length, mass, time, electric current, temperature, amount of substance, and light intensity (Table 1.1). All units other than the seven basic ones are *derived* units. Area, volume, and speed, for example, are all expressed with derived units. Units for the properties of length, mass, and time are introduced in this chapter. The remaining units will be introduced in later chapters as the properties they measure are discussed.

1.4 STANDARD UNITS FOR THE METRIC SYSTEM

If you consider all the properties of all the objects and events in your surroundings, the number seems overwhelming. Yet, close inspection of how properties are measured reveals that some properties are combinations of other properties (Figure 1.6). Volume, for example, is described by the three length measurements of length, width, and height. Area, on the other hand, is described by just the two length measurements of length and width. Length, however, cannot be defined in simpler terms of any other property. There are four properties that cannot be described in simpler terms, and all other properties are combinations of these four. For this reason, they are called the **fundamental properties.** A fundamental property cannot be defined in simpler terms other than to describe how it is measured. These four fundamental properties are (1) *length,* (2) *mass,* (3) *time,* and (4) *charge.* Used individually or in combinations, these four properties will describe or measure what you observe in nature. Metric units for measuring the fundamental properties of length, mass, and time will be described next. The fourth fundamental property, charge, is associated with electricity, and a unit for this property will be discussed in chapter 6.

LENGTH

The standard unit for length in the metric system is the **meter** (the symbol or abbreviation is m). The meter is defined as the distance that light travels in a vacuum during a certain time period, 1/299,792,458 second. The important thing to remember, however, is that the meter is the metric *standard unit* for length. A meter is slightly longer than a yard, 39.3 inches. It is approximately the distance from your left shoulder to the tip of your right hand when your arm is held straight out. Many doorknobs are about 1 meter above the floor. Think about these distances when you are trying to visualize a meter length.

MASS

The standard unit for mass in the metric system is the **kilogram** (kg). The kilogram is defined as the mass of a particular cylinder made of platinum and iridium, kept by the International Bureau of Weights and Measures in France. This is the only standard unit that is still defined in terms of an object. The property of mass is sometimes confused with the property of weight since they are directly proportional to each other at a given location on the surface of Earth. They are, however, two completely different properties and are measured with different units. All objects tend to maintain their state of rest or straight-line motion, and this property is called "inertia." The *mass* of an object is a measure of the inertia of an object. The *weight* of the object is a measure of the force of gravity on it. This distinction between weight and mass will be discussed in detail in chapter 2. For now, remember that weight and mass are not the same property.

TIME

The standard unit for time is the **second** (s). The second was originally defined as 1/86,400 of a solar day (1/60 × 1/60 × 1/24). Earth's spin was found not to be as constant as thought, so this old definition of one second had to be revised. Adopted in 1967, the new definition is based on a high-precision device known as an *atomic clock*. An atomic clock has a referent for a second that is provided by the characteristic vibrations of the cesium-133 atom. The atomic clock that was built at the National Institute of Standards and Technology in Boulder, Colorado, will neither gain nor lose a second in 20 million years!

1.5 METRIC PREFIXES

The metric system uses prefixes to represent larger or smaller amounts by factors of 10. Some of the more commonly used prefixes, their abbreviations, and their meanings are listed in Table 1.2. Suppose you wish to measure something smaller than the standard unit of length, the meter. The meter is subdivided into 10 equal-sized subunits called *decimeters*. The prefix *deci-* has a meaning of "one-tenth of," and it takes 10 decimeters (dm) to equal the length of 1 meter.

For even smaller measurements, each decimeter is divided into 10 equal-sized subunits called *centimeters*. It takes 10 centimeters (cm) to equal 1 decimeter and 100 centimeters to equal 1 meter. In a similar fashion, each prefix up or down the metric scale represents a simple increase or decrease by a factor of 10 (Figure 1.7).

When the metric system was established in 1791, the standard unit of mass was defined in terms of the mass of a certain volume of water. One cubic decimeter (1 dm^3) of pure water at 4°C was

TABLE 1.2

Some Metric Prefixes

Prefix	Symbol	Meaning	Unit Multiplier
exa-	E	quintillion	10^{18}
peta-	P	quadrillion	10^{15}
tera-	T	trillion	10^{12}
giga-	G	billion	10^{9}
mega-	M	million	10^{6}
kilo-	k	thousand	10^{3}
hecto-	h	hundred	10^{2}
deka-	da	ten	10^{1}
deci-	d	one-tenth	10^{-1}
centi-	c	one-hundredth	10^{-2}
milli-	m	one-thousandth	10^{-3}
micro-	μ	one-millionth	10^{-6}
nano-	n	one-billionth	10^{-9}
pico-	p	one-trillionth	10^{-12}
femto-	f	one-quadrillionth	10^{-15}
atto-	a	one-quintillionth	10^{-18}

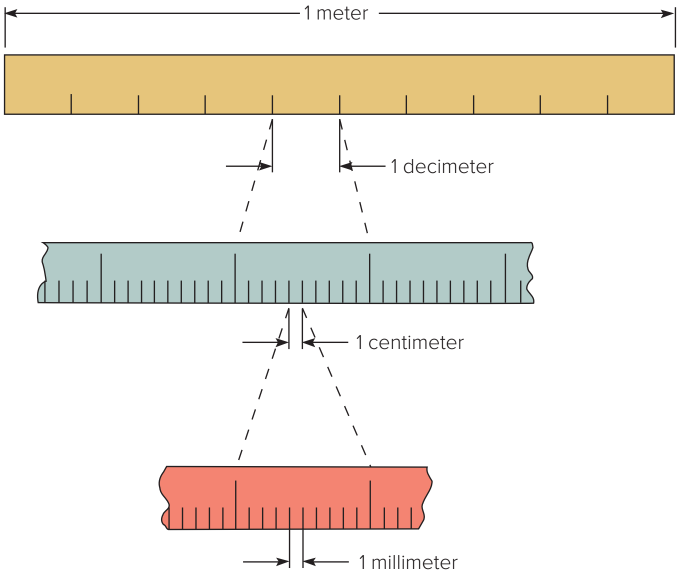


FIGURE 1.7 Compare the units shown here. How many millimeters fit into the space occupied by 1 centimeter? How many millimeters fit into the space of 1 decimeter? How many millimeters fit into the space of 1 meter? Can you express all these as multiples of 10?

defined to have a mass of 1 kilogram (kg). This definition was convenient because it created a relationship between length, mass, and volume. As illustrated in Figure 1.8, a cubic decimeter is 10 cm on each side. The volume of this cube is therefore 10 cm × 10 cm × 10 cm, or 1,000 cubic centimeters (abbreviated as cc or cm^3). Thus, a volume of 1,000 cm^3 of water has a mass of 1 kg. Since 1 kg is 1,000 g, 1 cm^3 of water has a mass of 1 g.

The volume of 1,000 cm^3 also defines a metric unit that is commonly used to measure liquid volume, the **liter** (L). For smaller amounts of liquid volume, the milliliter (mL) is used. The relationship between liquid volume, volume, and mass of water is therefore

$$1.0 \text{ L} \Rightarrow 1.0 \text{ dm}^3 \text{ and has a mass of } 1.0 \text{ kg}$$

or, for smaller amounts,

$$1.0 \text{ mL} \Rightarrow 1.0 \text{ cm}^3 \text{ and has a mass of } 1.0 \text{ g}$$

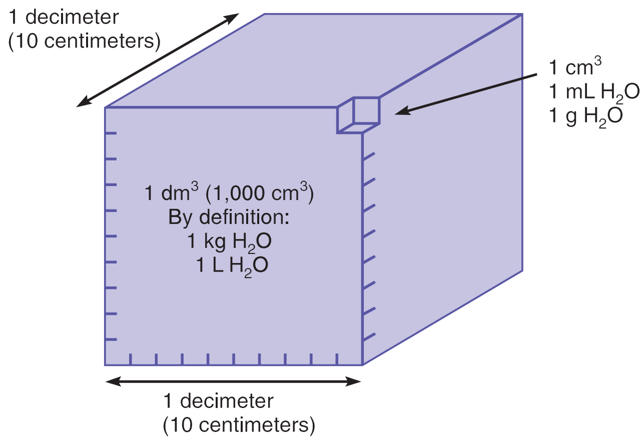


FIGURE 1.8 A cubic decimeter of water (1,000 cm^3) has a liquid volume of 1 L (1,000 mL) and a mass of 1 kg (1,000 g). Therefore, 1 cm^3 of water has a liquid volume of 1 mL and a mass of 1 g.

1.6 UNDERSTANDINGS FROM MEASUREMENTS

One of the more basic uses of measurement is to *describe* something in an exact way that everyone can understand. For example, if a friend in another city tells you that the weather has been "warm," you might not understand what temperature is being described. A statement that the air temperature is 70°F carries more exact information than a statement about "warm weather." The statement that the air temperature is 70°F contains two important concepts: (1) the numerical value of 70 and (2) the referent unit of degrees Fahrenheit. Note that both a numerical value and a unit are necessary to communicate a measurement correctly. Thus, weather reports describe weather conditions with numerically specified units; for example, 70° Fahrenheit for air temperature, 5 miles per hour for wind speed, and 0.5 inch for rainfall (Figure 1.9). When such numerically specified units are used in a description, or a weather report, everyone understands *exactly* the condition being described.

DATA

Measurement information used to describe something is called **data.** Data can be used to describe objects, conditions, events, or changes that might be occurring. You really do not know if the weather is changing much from year to year until you compare the yearly weather data. The data will tell you, for example, if the weather is becoming hotter or dryer or is staying about the same from year to year.

Let's see how data can be used to describe something and how the data can be analyzed for further understanding. The cubes illustrated in Figure 1.10 will serve as an example. Each cube can be described by measuring the properties of size and surface area.

First, consider the size of each cube. Size can be described by **volume,** which means *how much space something occupies.* The volume of a cube can be obtained by measuring and multiplying the length, width, and height. The data are

volume of cube *a*	1 cm^3
volume of cube *b*	8 cm^3
volume of cube *c*	27 cm^3

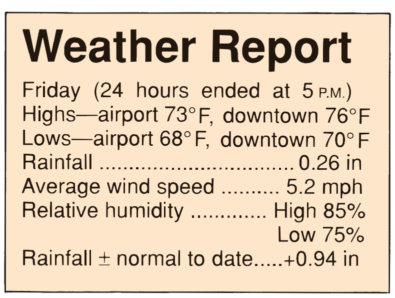

Weather Report
Friday (24 hours ended at 5 P.M.)
Highs—airport 73°F, downtown 76°F
Lows—airport 68°F, downtown 70°F
Rainfall .... 0.26 in
Average wind speed .... 5.2 mph
Relative humidity .... High 85%
Low 75%
Rainfall ± normal to date.....+0.94 in

FIGURE 1.9 A weather report gives exact information, data that describe the weather by reporting numerically specified units for each condition being described.

Now consider the surface area of each cube. **Area** means *the extent of a surface,* and each cube has six surfaces, or faces (top, bottom, and four sides). The area of any face can be obtained by measuring and multiplying length and width. The data for the three cubes describe them as follows:

	Volume	Surface Area
cube *a*	1 cm^3	6 cm^2
cube *b*	8 cm^3	24 cm^2
cube *c*	27 cm^3	54 cm^2

RATIOS AND GENERALIZATIONS

Data on the volume and surface area of the three cubes in Figure 1.10 describe the cubes, but whether they say anything about a relationship between the volume and surface area of a cube is difficult to tell. Nature seems to have a tendency to camouflage relationships, making it difficult to extract meaning from raw data. Seeing through the camouflage requires the use of mathematical techniques to expose patterns. Let's see how such techniques can be applied to the data on the three cubes and what the pattern means.

One mathematical technique for reducing data to a more manageable form is to expose patterns through a **ratio.** A ratio is a relationship between two numbers that is obtained when one number is divided by another number. Suppose, for example, that an instructor has 50 sheets of graph paper for a laboratory group of 25 students. The relationship, or ratio, between the number of sheets and the number of students is 50 papers to 25 students, and this can be written as 50 papers/25 students. This ratio is *simplified* by dividing 25 into 50, and the ratio becomes 2 papers/1 student. The 1 is usually understood (not stated), and the ratio is written as simply 2 papers/student. It is read as 2 papers "for each" student, or 2 papers "per" student. The concept of simplifying with a ratio is an important one, and you will see it time and again throughout science. It is important that you understand the meaning of *per* and *for each* when used with numbers and units.

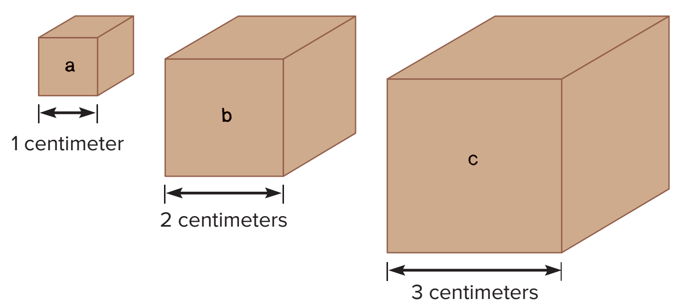


FIGURE 1.10 Cube *a* is 1 centimeter on each side, cube *b* is 2 centimeters on each side, and cube *c* is 3 centimeters on each side. These three cubes can be described and compared with data, or measurement information, but some form of analysis is needed to find patterns or meaning in the data.

Applying the ratio concept to the three cubes in Figure 1.10, the ratio of surface area to volume for the smallest cube, cube *a,* is 6 cm^2 to 1 cm^3, or

$$\frac{6\ \text{cm}^2}{1\ \text{cm}^3} = 6\ \frac{\text{cm}^2}{\text{cm}^3}$$

meaning there are 6 square centimeters of area *for each* cubic centimeter of volume.

The middle-sized cube, cube *b,* had a surface area of 24 cm^2 and a volume of 8 cm^3. The ratio of surface area to volume for this cube is therefore

$$\frac{24\ \text{cm}^2}{8\ \text{cm}^3} = 3\ \frac{\text{cm}^2}{\text{cm}^3}$$

meaning there are 3 square centimeters of area *for each* cubic centimeter of volume.

The largest cube, cube *c,* had a surface area of 54 cm^2 and a volume of 27 cm^3. The ratio is

$$\frac{54\ \text{cm}^2}{27\ \text{cm}^3} = 2\ \frac{\text{cm}^2}{\text{cm}^3}$$

or 2 square centimeters of area *for each* cubic centimeter of volume. Summarizing the ratio of surface area to volume for all three cubes, you have

small cube	a – 6:1
middle cube	b – 3:1
large cube	c – 2:1

Now that you have simplified the data through ratios, you are ready to generalize about what the information means. You can generalize that the surface-area-to-volume ratio of a cube *decreases* as the volume of a cube becomes larger. Reasoning from this generalization will provide an explanation for a number of related observations. For example, why does crushed ice melt faster than a single large block of ice with the same volume? The explanation is that the crushed ice has a larger surface-area-to-volume ratio than the large block, so more surface is exposed to warm air. If the generalization is found to be true for shapes other than cubes, you could explain why a log chopped into small chunks burns faster than the whole log. Further generalizing might enable you to predict if large potatoes would require more or less peeling than the same weight of small potatoes. When generalized explanations result in predictions that can be verified by experience, you gain confidence in the explanation. Finding patterns of relationships is a satisfying intellectual adventure that leads to understanding and generalizations that are frequently practical.

THE DENSITY RATIO

The power of using a ratio to simplify things, making explanations more accessible, is evident when you compare the simplified ratio 6 to 3 to 2 with the hodgepodge of numbers that you would have to consider without using ratios. The power of using the ratio technique is also evident when considering other properties of matter. Volume is a property that is sometimes confused with mass. Larger objects do not necessarily contain more matter than smaller objects. A large balloon, for example, is much larger than this book, but the book is much more massive than the balloon. The simplified way of comparing the mass of a particular volume is to find the ratio of mass to volume. This ratio is called **density,** which is defined as *mass per unit volume.* The *per* means "for each" as previously discussed, and *unit* means one, or each. Thus, "mass per unit volume" literally means the "mass of one volume" (Figure 1.11). The relationship can be written as

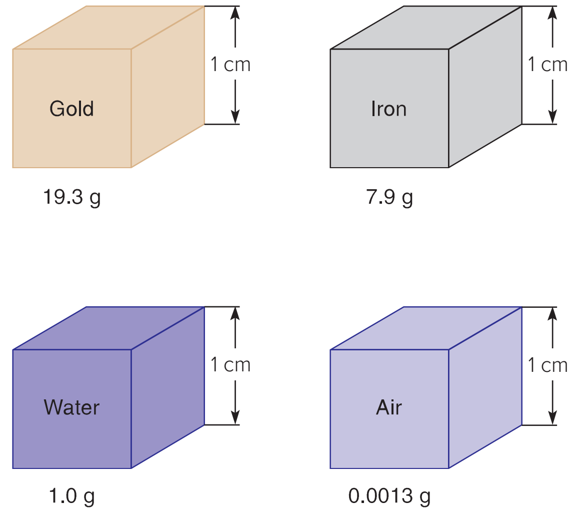


FIGURE 1.11 Equal volumes of different substances do not have the same mass, as these cube units show. Calculate the densities in g/cm^3. Do equal volumes of different substances have the same density? Explain.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

or

$$\rho = \frac{m}{V}$$

(ρ is the symbol for the Greek letter rho.)

equation 1.1

As with other ratios, density is obtained by dividing one number and unit by another number and unit. Thus, the density of an object with a volume of 5 cm^3 and a mass of 10 g is

$$\text{density} = \frac{10\ \text{g}}{5\ \text{cm}^3} = 2\ \frac{\text{g}}{\text{cm}^3}$$

The density in this example is the ratio of 10 g to 5 cm^3, or 10 g/5 cm^3, or 2 g to 1 cm^3. Thus, the density of the example object is the mass of *one* volume (a unit volume), or 2 g *for each* cm^3.

Any unit of mass and any unit of volume may be used to express density. The densities of solids, liquids, and gases are usually expressed in grams per cubic centimeter (g/cm^3), but the densities of liquids are sometimes expressed in grams per milliliter (g/mL). Using SI standard units, densities are expressed as kg/m^3. Densities of some common substances are shown in Table 1.3.

TABLE 1.3

Densities (ρ) of Some Common Substances

	g/cm^3
Aluminum	2.70
Copper	8.96
Iron	7.87
Lead	11.4
Water	1.00
Seawater	1.03
Mercury	13.6
Gasoline	0.680

If matter is distributed the same throughout a volume, the *ratio* of mass to volume will remain the same no matter what mass and volume are being measured. Thus, a teaspoonful, a cup, and a lake full of freshwater at the same temperature will all have a density of about 1 g/cm^3 or 1 kg/L. A given material will have its own unique density; example 1.1 shows how density can be used to identify an unknown substance. For help with significant figures, see appendix A (p. A3).

CONCEPTS *Applied*

Density Matters—Sharks and Cola Cans

What do a shark and a can of cola have in common? Sharks are marine animals that have an internal skeleton made entirely of cartilage. These animals have no swim bladder to adjust their body density in order to maintain their position in the water; therefore, they must constantly swim or they will sink. The bony fish, on the other hand, have a skeleton composed of bone, and most also have a swim bladder. These fish can regulate the amount of gas in the bladder to control their density. Thus, the fish can remain at a given level in the water without expending large amounts of energy.

Have you ever noticed the different floating characteristics of cans of the normal version of a carbonated cola beverage and a diet version? The surprising result is that the normal version usually sinks and the diet version usually floats. This has nothing to do with the amount of carbon dioxide in the two drinks. It is a result of the increase in density from the sugar added to the normal version, while the diet version has much less of an artificial sweetener that is much sweeter than sugar. So, the answer is that sharks and regular cans of cola both sink in water.

EXAMPLE 1.1

Two blocks are on a table. Block A has a volume of 30.0 cm^3 and a mass of 81.0 g. Block B has a volume of 50.0 cm^3 and a mass of 135 g. Which block has the greater density? If the two blocks have the same density, what material are they? (See Table 1.3.)

SOLUTION

Density is defined as the ratio of the mass of a substance per unit volume. Assuming the mass is distributed equally throughout the volume, you could assume that the ratio of mass to volume is the same no matter what quantities of mass and volume are measured. If you can accept this assumption, you can use equation 1.1 to determine the density.

Block A

mass (m) = 81.0 g
volume (V) = 30.0 cm^3
density = ?

$$\rho = \frac{m}{V} = \frac{81.0\ \text{g}}{30.0\ \text{cm}^3} = 2.70\ \frac{\text{g}}{\text{cm}^3}$$

Block B

mass (m) = 135 g
volume (V) = 50.0 cm^3
density = ?

$$\rho = \frac{m}{V} = \frac{135\ \text{g}}{50.0\ \text{cm}^3} = 2.70\ \frac{\text{g}}{\text{cm}^3}$$

As you can see, both blocks have the same density. Inspecting Table 1.3, you can see that aluminum has a density of 2.70 g/cm^3, so both blocks must be aluminum.

EXAMPLE 1.2

A rock with a volume of 4.50 cm^3 has a mass of 15.0 g. What is the density of the rock? (Answer: 3.33 g/cm^3)

CONCEPTS *Applied*

A Dense Textbook?

What is the density of this book? Measure the length, width, and height of this book in cm, then multiply to find the volume in cm^3. Use a scale to find the mass of this book in grams. Compute the density of the book by dividing the mass by the volume. Compare the density in g/cm^3 with other substances listed in Table 1.3.

Myths, Mistakes, & Misunderstandings

Tap a Can?

Some people believe that tapping on the side of a can of carbonated beverage will prevent it from foaming over when the can is opened. Is this true or a myth? Set up a controlled experiment (see p. 15) to compare opening cold cans of carbonated beverage that have been tapped with cans that have not been tapped. Are you sure you have controlled all the other variables?

SYMBOLS AND EQUATIONS

In the previous section, the relationship of density, mass, and volume was written with symbols. Density was represented by ρ, the lowercase letter rho in the Greek alphabet, mass was represented by *m,* and volume by *V.* The use of such symbols is established and accepted by convention, and these symbols are like the vocabulary of a foreign language. You learn what the symbols mean by use and practice, with the understanding that *each symbol stands for a very specific property or concept.* The symbols actually represent **quantities,** or *measured properties.* The symbol *m* thus represents a quantity of mass that is specified by a number and a unit, for example, 16 g. The symbol *V* represents a quantity of volume that is specified by a number and a unit, such as 17 cm^3.

Symbols

Symbols usually provide a clue about which quantity they represent, such as *m* for mass and *V* for volume. However, in some cases, two quantities start with the same letter, such as volume and velocity, so the uppercase letter is used for one (*V* for volume) and the lowercase letter is used for the other (*v* for velocity). There are more quantities than upper- and lowercase letters, however, so letters from the Greek alphabet are also used, for example, ρ for mass density. Sometimes a subscript is used to identify a quantity in a particular situation, such as v_i for initial, or beginning, velocity and v_f for final velocity. Some symbols are also used to carry messages; for example, the Greek letter delta (Δ) is a message that means "the change in" a value. Other message symbols are the symbol $\therefore$, which means "therefore," and the symbol $\propto$, which means "is proportional to."

Equations

Symbols are used in an **equation,** a statement that describes a relationship where *the quantities on one side of the equal sign are identical to the quantities on the other side.* The word *identical* refers to both the numbers and the units. Thus, in the equation describing the property of density, $\rho = m/V$, the numbers on both sides of the equal sign are identical (e.g., $5 = 10/2$). The units on both sides of the equal sign are also identical (e.g., $g/cm^3 = g/cm^3$).

Equations are used to (1) *describe a property,* (2) *define a concept,* or (3) *describe how quantities change relative to each other.* Understanding how equations are used in these three classes is basic to successful problem solving and comprehension of physical science.

Describing a property. You have already learned that the compactness of matter is described by the property called density. Density is a ratio of mass to a unit volume, or $\rho = m/V$. The key to understanding this property is to understand the meaning of a ratio and what "per" or "for each" means. Other examples of properties that can be defined by ratios are how fast something is moving (speed) and how rapidly a speed is changing (acceleration).

Defining a concept. A physical science concept is sometimes defined by specifying a measurement procedure. This is called an *operational definition* because a procedure is established that defines a concept and tells you how to measure it. Concepts of what is meant by force can be defined by measurement procedures.

Describing how quantities change relative to each other. The term **variable** refers to a specific quantity of an object or event that can have different values. Your weight, for example, is a variable because it can have a different value on different days. The rate of your heartbeat, the number of times you breathe each minute, and your blood pressure are also variables. Any quantity describing an object or event can be considered a variable, including the conditions that result in such things as your current weight, pulse, breathing rate, or blood pressure.

As an example of relationships between variables, consider that your weight changes in size in response to changes in other variables, such as the amount of food you eat. With all other factors being equal, a change in the amount of food you eat results in a change in your weight, so the variables of amount of food eaten and weight change together in the same ratio. A *graph* is used to help you picture relationships between variables (see "Simple Line Graph" on p. A6).

When two variables increase (or decrease) together in the same ratio, they are said to be in **direct proportion.** When two variables are in direct proportion, *an increase or decrease in one variable results in the same relative increase or decrease in a second variable.* Recall that the symbol $\propto$ means "is proportional to," so the relationship is

$$\text{amount of food consumed} \propto \text{weight gain}$$

Variables do not always increase or decrease together in direct proportion. Sometimes one variable *increases* while a second variable *decreases* in the same ratio. This is an **inverse proportion** relationship. Other common relationships include one variable increasing in proportion to the *square* or to the *inverse square* of a second variable. Here are the forms of these four different types of proportional relationships:

Direct	$a \propto b$
Inverse	$a \propto 1/b$
Square	$a \propto b^2$
Inverse square	$a \propto 1/b^2$

Proportionality Statements

Proportionality statements describe in general how two variables change relative to each other, but a proportionality statement is *not* an equation. For example, consider the last time you filled your fuel tank at a service station (Figure 1.12). You could say that the volume of gasoline in an empty tank you are filling is directly proportional to the amount of time that the fuel pump was running, or

$$\text{volume} \propto \text{time}$$

This is not an equation because the numbers and units are not identical on both sides. Considering the units, for example, it should be clear that minutes do not equal liters; they are two different quantities. To make a statement of proportionality into an equation, you need to apply a **proportionality constant,**

FIGURE 1.12 The volume of fuel you have added to the fuel tank is directly proportional to the amount of time that the fuel pump has been running. This relationship can be described with an equation by using a proportionality constant. West Coast Surfer/SuperStock

which is sometimes given the symbol *k*. For the fuel pump example, the equation is

$$\text{volume} = (\text{time})(\text{constant})$$

or

$$V = tk$$

In the example, the constant is the flow of gasoline from the pump in L/min (a ratio). Assume the rate of flow is 40 L/min. In units, you can see why the statement is now an equality.

$$\mathrm{L} = (\mathrm{min})\left(\frac{\mathrm{L}}{\mathrm{min}}\right)$$

$$\mathrm{L} = \frac{\cancel{\mathrm{min}} \times \mathrm{L}}{\cancel{\mathrm{min}}}$$

$$\mathrm{L} = \mathrm{L}$$

A proportionality constant in an equation might be a **numerical constant,** a constant that is without units. Such numerical constants are said to be dimensionless, such as 2 or 3.

CONCEPTS *Applied*

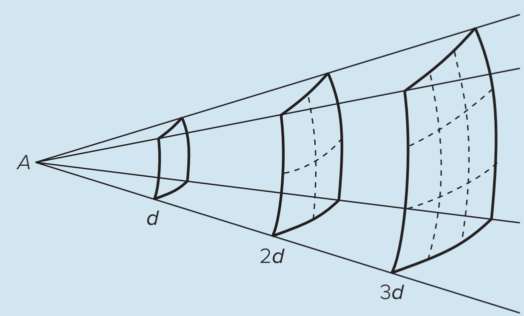
Inverse Square Relationship

An inverse square relationship between energy and distance is found in light, sound, gravitational force, electric fields, nuclear radiation, and any other phenomena that spread equally in all directions from a source.

Box Figure 1.1 could represent any of the phenomena that have an inverse square relationship, but let us assume it is showing a light source and how the light spreads at a certain distance (*d*), at twice that distance (2*d*), and at three times that distance (3*d*). As you can see, light twice as far from the source is spread over four times the area and will therefore have one-fourth the intensity. This is the same as $\frac{1}{2^2}$, or $\frac{1}{4}$.

Light three times as far from the source is spread over nine times the area and will therefore have one-ninth the intensity. This is the same as $\frac{1}{3^2}$, or $\frac{1}{9}$, again showing an inverse square relationship.

You can measure the inverse square relationship by moving an overhead projector so its light is shining on a wall (see distance *d* in Box Figure 1.1). Use a light meter or some other way of measuring the intensity of light. Now move the projector to double the distance from the wall. Measure the increased area of the projected light on the wall, and again measure the intensity of the light. What relationship did you find between the light intensity and distance?



BOX FIGURE 1.1 How much would light moving from point *A* spread out at twice the distance (2*d*) and three times the distance (3*d*)? What would this do to the brightness of the light?

SCIENCE *Sketch*

Draw on Box Figure 1.1 (*or on paper*) to show how much light would be spread out at five times the distance (5*d*).

Some of the more important numerical constants have their own symbols; for example, the ratio of the circumference of a circle to its diameter is known as π (pi). The numerical constant of π does not have units because the units cancel when the ratio is simplified by division (Figure 1.13). The value of π is usually rounded to 3.14, and an example of using this numerical constant in an equation is that the area of a circle equals π times the radius squared ($A = \pi r^2$).

The flow of gasoline from a pump is an example of a constant that has dimensions (40 L/min). Of course the value of this

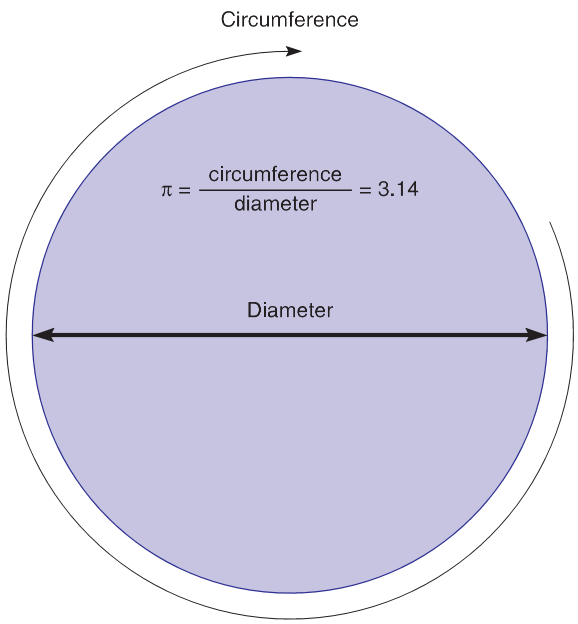


FIGURE 1.13 The ratio of the circumference of *any* circle to the diameter of that circle is always π, a numerical constant that is usually rounded to 3.14. Pi does not have units because they cancel in the ratio.

constant will vary with other conditions, such as the particular fuel pump used and how far the handle on the pump hose is depressed, but it can be considered to be a constant under the same conditions for any experiment.

HOW TO SOLVE PROBLEMS

The activity of problem solving is made easier by using certain techniques that help organize your thinking. One such technique is to follow a format, such as the following procedure:

Step 1: Read through the problem and *make a list* of the variables with their symbols on the left side of the page, including the unknown with a question mark.

Step 2: Inspect the list of variables and the unknown, and identify the equation that expresses a relationship between these variables. A list of equations discussed in each chapter is found at the end of that chapter. *Write the equation* on the right side of your paper, opposite the list of symbols and quantities.

Step 3: If necessary, *solve the equation* for the variable in question. This step must be done before substituting any numbers or units in the equation. This simplifies things and keeps down confusion that might otherwise result. If you need help solving an equation, see the section on this topic in appendix A.

Step 4: If necessary, *convert unlike units* so they are all the same. For example, if a time is given in seconds and a speed is given in kilometers per hour, you should convert the km/h to m/s. Again, this step should be done at this point in the procedure to avoid confusion or incorrect operations in a later step. If you need help converting units, see the section on this topic in appendix A.

Step 5: Now you are ready to *substitute the number value and unit* for each symbol in the equation (except the unknown). Note that it might sometimes be necessary to perform a "subroutine" to find a missing value and unit for a needed variable.

Step 6: Do the indicated *mathematical operations* on the numbers and on the units. This is easier to follow if you first separate the numbers and units, as shown in the example that follows and in the examples throughout this text. Then perform the indicated operations on the numbers and units as separate steps, showing all work. If you are not sure how to read the indicated operations, see the section on "Symbols and Operations" in appendix A.

Step 7: Now ask yourself if the number seems reasonable for the question that was asked, and ask yourself if the unit is correct. For example, 250 m/s is way too fast for a running student, and the unit for speed is not liters.

Step 8: *Draw a box* around your answer (numbers and units) to communicate that you have found what you were looking for. The box is a signal that you have finished your work on this problem.

For an example problem, use the equation from the previous section describing the variables of a fuel pump, $V = tk$, to predict how long it will take to fill an empty 80-liter tank. Assume $k = 40$ L/min.

Step 1

$V = 80 \text{ L}$ $\qquad V = tk$ **Step 2**

$k = 40 \text{ L/min}$ $\qquad \dfrac{V}{k} = \dfrac{tk}{k}$ **Step 3**

$t = ?$

$$t = \frac{V}{k}$$

(no conversion needed for this problem) **Step 4**

$$t = \frac{80 \text{ L}}{40 \dfrac{\text{L}}{\text{min}}} \qquad \textbf{Step 5}$$

$$= \frac{80}{40}\,\frac{\text{L}}{1} \times \frac{\text{min}}{\text{L}} \qquad \textbf{Step 6}$$

$$= \boxed{2 \text{ min}} \qquad \textbf{Step 7}$$

Note that procedure step 4 was not required in this solution.

This formatting procedure will be demonstrated throughout this text in example problems and in the solutions to problems found in appendix E. Note that each of the chapters with problems has parallel exercises. The exercises in groups A and B cover the same concepts. If you cannot work a problem in group B, look for the parallel problem in group A. You will find a solution to this problem, in the previously described format, in appendix E. Use this parallel problem solution as a model to help you solve the problem in group B. If you follow the suggested formatting procedures and seek help from the appendix as needed, you will find that problem solving is a simple, fun activity that helps you to learn to think in a new way. Here are some more considerations that will prove helpful.

1. Read the problem carefully, perhaps several times, to understand the problem situation. Make a sketch to help you visualize and understand the problem in terms of the real world.
2. Be alert for information that is not stated directly. For example, if a moving object "comes to a stop," you know that the final velocity is zero, even though this was not stated outright. Likewise, questions about "how far?" are usually asking a question about distance, and questions about "how long?" are usually asking a question about time. Such information can be very important in procedure step 1, the listing of quantities and their symbols. Overlooked or missing quantities and symbols can make it difficult to identify the appropriate equation.
3. Understand the meaning and concepts that an equation represents. An equation represents a *relationship* that exists between variables. Understanding the relationship helps you to identify the appropriate equation or equations by inspection of the list of known and unknown quantities (procedure step 2). You will find a list of the equations being considered at the end of each chapter. Information about the meaning and the concepts that an equation represents is found within each chapter.
4. Solve the equation before substituting numbers and units for symbols (procedure step 3). A helpful discussion of the mathematical procedures required, with examples, is in appendix A.
5. Note whether the quantities are in the same units. A mathematical operation requires the units to be the same; for example, you cannot add nickels, dimes, and quarters until you first convert them all to the same unit of money. Likewise, you cannot correctly solve a problem if one time quantity is in seconds and another time quantity is in hours. The quantities must be converted to the same units before anything else is done (procedure step 4). There is a helpful section on how to use conversion ratios in appendix A.
6. Perform the required mathematical operations on the numbers and the units as if they were two separate problems (procedure step 6). You will find that following this step will facilitate problem-solving activities because the units you obtain will tell you if you have worked the problem correctly. If you just write the units that you think should appear in the answer, you have missed this valuable self-check.
7. Be aware that not all learning takes place in a given time frame and that solutions to problems are not necessarily arrived at "by the clock." If you have spent a half an hour or so unsuccessfully trying to solve a particular problem, move on to another problem or do something entirely different for a while. Problem solving often requires time for something to happen in your brain. If you move on to some other activity, you might find that the answer to a problem that you have been stuck on will come to you "out of the blue" when you are not even thinking about the problem. This unexpected revelation of solutions is common to many real-world professions and activities that involve thinking.

Example Problem

Mercury is a liquid metal with a mass density of 13.6 g/cm^3. What is the mass of 10.0 cm^3 of mercury?

Solution

The problem gives two known quantities, the mass density (ρ) of mercury and a known volume (V), and identifies an unknown quantity, the mass (m) of that volume. Make a list of these quantities:

$\rho = 13.6 \text{ g/cm}^3$

$V = 10.0 \text{ cm}^3$

$m = ?$

The appropriate equation for this problem is the relationship between density (ρ), mass (m), and volume (V):

$$\rho = \frac{m}{V}$$

The unknown in this case is the mass, m. Solving the equation for m, by multiplying both sides by V, gives:

$$V\rho = \frac{mV}{V}$$

$$V\rho = m, \text{ or}$$

$$m = V\rho$$

Now you are ready to substitute the known quantities in the equation:

$$m = \left(13.6 \frac{\text{g}}{\text{cm}^3}\right)(10.0 \text{ cm}^3)$$

And perform the mathematical operations on the numbers and on the units:

$$m = (13.6)(10.0)\left(\frac{\text{g}}{\text{cm}^3}\right)(\text{cm}^3)$$

$$= 136 \frac{\text{g} \cdot \text{cm}^3}{\text{cm}^3}$$

$$= \boxed{136 \text{ g}}$$

1.7 THE NATURE OF SCIENCE

Most humans are curious, at least when they are young, and are motivated to understand their surroundings. These traits have existed since antiquity and have proven to be a powerful motivation. In recent times, the need to find out has motivated the launching of space probes to learn what is "out there," and humans have visited the Moon to satisfy their curiosity. Curiosity and the motivation to understand nature were no less powerful in the past than today. Over two thousand years ago, the Greeks lacked the tools and technology of today and could only make conjectures about the workings of nature. These early seekers of understanding are known as *natural philosophers,* and they observed, thought about, and wrote about the workings of all of nature. They are called philosophers because their understandings came from reasoning only, without experimental evidence. Nonetheless, some of their ideas were essentially correct and are still in use today. For example, the idea of matter being composed of *atoms* was first reasoned by certain Greeks in the fifth century B.C. The idea of *elements,* basic components that make up matter, was developed much earlier but refined by the ancient Greeks in the fourth century B.C. The concept of what the elements are and the concept of the nature of atoms have changed over time, but the ideas first came from ancient natural philosophers.

THE SCIENTIFIC METHOD

Some historians identify the time of Galileo and Newton, approximately three hundred years ago, as the beginning of modern science. Like the ancient Greeks, Galileo and Newton were interested in studying all of nature. Since the time of Galileo and Newton, the content of physical science has increased in scope and specialization, but the basic means of acquiring understanding, the scientific investigation, has changed little. A *scientific investigation* provides understanding through *experimental evidence* as opposed to the conjectures based on the "thinking only" approach of the ancient natural philosophers. In chapter 2, for example, you will learn how certain ancient Greeks described how objects fall toward Earth with a thought-out, or reasoned, explanation. Galileo, on the other hand, changed how people thought of falling objects by developing explanations from both creative thinking and precise measurement of physical quantities, providing experimental evidence for his explanations. Experimental evidence provides explanations today, much as it did for Galileo, as relationships are found from precise measurements of physical quantities. Thus, scientific knowledge about nature has grown as measurements and investigations have led to understandings that lead to further measurements and investigations.

What is a scientific investigation, and what methods are used to conduct one? Attempts have been made to describe scientific methods in a series of steps (define problem, gather data, make hypothesis, test, make conclusion), but no single description has ever been satisfactory to all concerned. Scientists do similar things in investigations, but there are different approaches and different ways to evaluate what is found. Overall, the similar things might look like this:

1. Observe some aspect of nature.
2. Propose an explanation for something observed.
3. Use the explanation to make predictions.
4. Test predictions by doing an experiment or by making more observations.
5. Modify explanation as needed.
6. Return to step 3.

The exact approach used depends on the individual doing the investigation and on the field of science being studied.

Another way to describe what goes on during a scientific investigation is to consider what can be generalized. There are at least three separate activities that seem to be common to scientists in different fields as they conduct scientific investigations, and these generalizations look like this:

- Collecting observations
- Developing explanations
- Testing explanations

No particular order or routine can be generalized about these common elements. In fact, individual scientists might not even be involved in all three activities. Some, for example, might spend all of their time out in nature, "in the field" collecting data and generalizing about their findings. This is an acceptable means of investigation in some fields of science. Other scientists might spend all of their time indoors at computer terminals developing theoretical equations to explain the generalizations made by others. Again, the work at a computer terminal is an acceptable means of scientific investigation. Thus, many of today's specialized scientists never engage in a five-step process. This is one reason why many philosophers of science argue that there is no such thing as *the* scientific method. There are common activities of observing, explaining, and testing in scientific investigations in different fields, and these activities will be discussed next.

EXPLANATIONS AND INVESTIGATIONS

Explanations in the natural sciences are concerned with things or events observed, and there can be several different ways to develop or create explanations. In general, explanations can come from the results of experiments, from an educated guess, or just from imaginative thinking. In fact, there are even several examples in the history of science of valid explanations being developed from dreams.

Explanations go by various names, each depending on the intended use or stage of development. For example, an explanation in an early stage of development is sometimes called a *hypothesis*. A **hypothesis** is a tentative thought- or experiment-derived explanation. It must be compatible with observations and must provide understanding of some aspect of nature, but the key word here is *tentative*. A hypothesis is tested by experiment and is rejected, or modified, if a single observation or test does not fit.

The successful testing of a hypothesis may lead to the design of experiments, or it could lead to the development of another hypothesis, which could, in turn, lead to the design of yet more experiments, which could lead to.… As you can see, this is a branching, ongoing process that is very difficult to describe in specific terms. In addition, it can be difficult to identify an end-point in the process that you could call a conclusion. The search for new concepts to explain experimental evidence may lead from hypothesis to new ideas, which results in more new hypotheses. This is why one of the best ways to understand scientific methods is to study the history of science. Or do the activity of science yourself by planning, then conducting experiments.

Testing a Hypothesis

In some cases, a hypothesis may be tested by simply making some simple observations. For example, suppose you hypothesized that the height of a bounced ball depends only on the height from which the ball is dropped. You could test this by observing different balls being dropped from several different heights and recording how high each bounced.

Another common method for testing a hypothesis involves devising an experiment. An **experiment** is a re-creation of an event or occurrence in a way that enables a scientist to support or disprove a hypothesis. This can be difficult, since an event can be influenced by a great many different things.

Science and Society

Basic and Applied Research

Science is the process of understanding your environment. It begins with making observations, creating explanations, and conducting research experiments. New information and conclusions are based on the results of the research.

There are two types of scientific research: basic and applied. Basic research is driven by a search for understanding and may or may not have practical applications. Examples of basic research include seeking understandings about how the solar system was created, finding new information about matter by creating a new element in a research lab, or mapping temperature variations on the bottom of the Chesapeake Bay. Such basic research expands our knowledge but will not lead to practical results.

Applied research has a goal of solving some practical problem rather than just looking for answers. Examples of applied research include the creation and testing of a new, highly efficient fuel cell to run cars on hydrogen fuel, improving the energy efficiency of the refrigerator, or creating a faster computer chip from new materials.

Whether research is basic or applied depends somewhat on the time frame. If a practical use cannot be envisioned in the future, then it is definitely basic research. If a practical use is immediate, then the work is definitely applied research. If a practical use is developed some time in the future, then the research is partly basic and partly applied. For example, when the laser was invented, there was no practical use for it. It was called "an answer waiting for a question." Today, the laser has many, many practical applications.

Knowledge gained by basic research has sometimes resulted in the development of technological breakthroughs. On the other hand, other basic research—such as learning how the solar system formed—has no practical value other than satisfying our curiosity.

QUESTIONS TO DISCUSS

1. Should funding priorities go to basic research, applied research, or both?
2. Should universities concentrate on basic research and industries concentrate on applied research, or should both do both types of research?
3. Should research-funding organizations specify which types of research should be funded?

For example, suppose someone tells you that soup heats to the boiling point faster than plain water heats. Is this true? How can you find the answer to this question? The time required to boil a can of soup might depend on a number of things: the composition of the soup, how much soup is in the pan, what kind of pan is used, the nature of the stove, the size of the burner, how high the temperature is set, environmental factors such as the humidity and temperature, and more factors. It might seem that answering a simple question about the time involved in boiling soup is an impossible task. To help unscramble such situations, scientists sometimes use what is known as a two-group *controlled experiment.* A **controlled experiment** compares two situations in which all the influencing factors are identical except one. The situation used as the basis of comparison is called the *control,* and the other is called the *experimental*. The single influencing factor that is allowed to be different in the experimental group is called the *experimental variable.*

The situation involving the time required to boil soup and water would have to be broken down into a number of simple questions. Each question would provide the basis on which experimentation would occur. Each experiment would provide information about a small part of the total process of heating liquids. For example, in order to test the hypothesis that soup will begin to boil before water, an experiment could be performed in which soup is brought to a boil (the experimental group), while water is brought to a boil in the control group. Every factor in the control group is *identical* to the factors in the experimental group except the experimental variable—the soup factor. After the experiment, the new data (facts) are gathered and analyzed. If there were no differences between the two groups, you could conclude that the soup variable evidently did not have a cause-and-effect relationship with the time needed to come to a boil (i.e., soup was not responsible for the time to boil). However, if there were a difference, it would be likely that this variable was responsible for the difference between the control and experimental groups. In the case of the time to come to a boil, you would find that soup indeed does boil faster than water alone. If you doubt this, why not do the experiment yourself?

Accept Results?

Scientists are not likely to accept the results of a single experiment, since it is possible that a random event that had nothing to do with the experiment could have affected the results and caused people to think there was a cause-and-effect relationship when none existed. For example, the density of soup is greater than the density of water, and this might be the important factor. A way to overcome this difficulty would be to test a number of different kinds of soup with different densities. When there is only one variable, many replicates (copies) of the same experiment are conducted, and the consistency of the results determines how convincing the experiment is.

Furthermore, scientists often apply statistical tests to the results to help decide in an impartial manner if the results obtained are *valid* (meaningful; fit with other knowledge), are *reliable* (give the same results repeatedly), and show cause-and-effect or if they are just the result of random events.

Patterns and experimental results are shared through *scientific communication*. This can be as simple as scientists sharing experimental findings by e-mail. Results are also checked and confirmed by publishing articles in journals. Such articles enable scientists to know what other scientists have done, but they also communicate ideas as well as the thinking processes. Scientific communication ensures that results and thinking processes are confirmed by other scientists. It also can lead to new discoveries based on the work of others.

Other Considerations

As you can see from the discussion of the nature of science, a scientific approach to the world requires a certain way of thinking. There is an insistence on ample supporting evidence by numerous studies rather than easy acceptance of strongly stated opinions. Scientists must separate opinions from statements of fact. A scientist is a healthy skeptic.

Careful attention to detail is also important. Since scientists publish their findings and their colleagues examine their work, there is a strong desire to produce careful work that can be easily defended. This does not mean that scientists do not speculate and state opinions. When they do, however, they take great care to clearly distinguish fact from opinion.

There is also a strong ethic of honesty. Scientists are not saints, but the fact that science is conducted out in the open in front of one's peers tends to reduce the incidence of dishonesty. In addition, the scientific community strongly condemns and severely penalizes those who steal the ideas of others, perform shoddy science, or falsify data. Any of these infractions could lead to the loss of one's job and reputation.

Science is also limited by the ability of people to pry understanding from the natural world. People are fallible and do not always come to the right conclusions, because information is lacking or misinterpreted, but science is self-correcting. As new information is gathered, old, incorrect ways of thinking must be changed or discarded. For example, at one time people were sure that the Sun went around Earth. They observed that the Sun rose in the east and traveled across the sky to set in the west. Since they could not feel Earth moving, it seemed perfectly logical that the Sun traveled around Earth. Once they understood that Earth rotated on its axis, people began to understand that the rising and setting of the Sun could be explained in other ways. A completely new concept of the relationship between the Sun and Earth developed.

Although this kind of study seems rather primitive to us today, this change in thinking about the Sun and Earth was a very important step in understanding the universe and how the various parts are related to one another. This background information was built upon by many generations of astronomers and space scientists, and it finally led to space exploration.

People also need to understand that science cannot answer all the problems of our time. Although science is a powerful tool, there are many questions it cannot answer and many problems it cannot solve. The behavior and desires of people generate most of the problems societies face. Famine, drug abuse, and pollution are human-caused and must be resolved by humans. Science may provide some tools for social planners, politicians, and ethical thinkers, but science does not have, nor does it attempt to provide, answers for the problems of the human race. Science is merely one of the tools at our disposal.

CONCEPTS *Applied*

Seekers of Pseudoscience

See what you can find out about some recent claims that might not stand up to direct scientific testing. Look into the scientific testing—or lack of testing—behind claims made in relation to cold fusion, cloning human beings, a dowser carrying a forked stick to find water, psychics hired by police departments, Bigfoot, the Bermuda Triangle, and others you might wish to investigate.

LAWS AND PRINCIPLES

Sometimes you can observe a series of relationships that seem to happen over and over. There is a popular saying, for example, that "if anything can go wrong, it will." This is called Murphy's law. It is called a *law* because it describes a relationship between events that seems to happen time after time. If you drop a slice of buttered bread, for example, it can land two ways, butter side up or butter side down. According to Murphy's law, it will land butter side down. With this example, you know at least one way of testing the validity of Murphy's law.

Another "popular saying" type of relationship seems to exist between the cost of a houseplant and how long it lives. You could call it the "law of houseplant longevity" that the life span of a houseplant is inversely proportional to its purchase price. This "law" predicts that a ten-dollar houseplant will wilt and die within a month, but a fifty-cent houseplant will live for years. The inverse relationship is between the variables of (1) cost and (2) life span, meaning the more you pay for a plant, the shorter the time it will live. This would also mean that inexpensive plants will live for a long time. Since the relationship seems to occur time after time, it is called a "law."

A **scientific law** describes an important relationship that is observed in nature to occur consistently time after time. Basically, scientific laws describe *what* happens in nature. The law is often identified with the name of a person associated with the formulation of the law. For example, with all other factors being equal, an increase in the temperature of the air in a balloon results in an increase in its volume. Likewise, a decrease in the temperature results in a decrease in the total volume of the balloon. The volume of the balloon varies directly with the temperature of the air in the balloon, and this can be observed to occur consistently time after time. This relationship was first discovered in the latter part of the eighteenth century by two French scientists, A. C. Charles and Joseph Gay-Lussac. Today, the relationship is sometimes called *Charles' law* (Figure 1.14). When you read about a scientific *law,* you should remember that a law is a statement that means something about a relationship that you can observe time after time in nature.

Have you ever heard someone state that something behaved a certain way *because* of a scientific principle or law? For example, a big truck accelerated slowly *because* of Newton's laws of motion. Perhaps this person misunderstands the nature of scientific principles and laws. Scientific principles and laws do not dictate

Verbal: The volume of a gas is directly proportional to the (absolute) temperature for a given amount if the pressure is constant.

Equation: $\Delta V = \Delta T k$

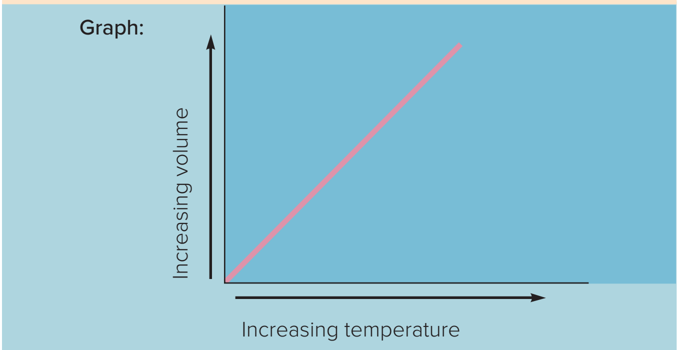


FIGURE 1.14 A relationship between variables can be described in at least three different ways: (1) verbally, (2) with an equation, and (3) with a graph. This figure illustrates the three ways of describing the relationship known as Charles' law.

SCIENCE *Sketch*

Draw on Figure 1.14 (*or on paper*) an illustration of Charles' law by drawing two air-filled balloons, with one heated to twice the temperature, to represent the relationship between variables of volume and temperature.

the behavior of objects; they simply describe it. They do not say how things ought to act but rather how things *do* act. A scientific principle or law is *descriptive;* it describes how things act.

A **scientific principle** describes a more specific set of relationships than is usually identified in a law. The difference between a scientific principle and a scientific law is usually one of the extent of the phenomena covered by the explanation, but there is not always a clear distinction between the two. As an example of a scientific principle, consider Archimedes' principle. This principle is concerned with the relationship between an object, a fluid, and buoyancy, which is a specific phenomenon.

MODELS AND THEORIES

Often the part of nature being considered is too small or too large to be visible to the human eye, and the use of a *model* is needed. A **model** (Figure 1.15) is a description of a theory or idea that accounts for all known properties. The description can come in many different forms, such as a physical model, a computer model, a sketch, an analogy, or an equation. No one has ever seen the whole solar system, for example, and all you can see in the real world is the movement of the Sun, Moon, and planets against a background of stars. A physical model or sketch of the solar system, however, will give you a pretty good idea of what the solar system might look like. The physical model and the sketch are both models, since they both give you a mental picture of the solar system.

At the other end of the size scale, models of atoms and molecules are often used to help us understand what is happening in this otherwise invisible world. A container of small, bouncing rubber balls can be used as a model to explain the relationships of Charles' law. This model helps you see what happens to invisible particles of air as the temperature, volume, or pressure of the gas changes. Some models are better than others are, and models constantly change as our understanding evolves. Early twentieth-century models of atoms, for example, were based on a "planetary model," in which electrons moved around the nucleus as planets move around the Sun. Today, the model has changed as our understanding of the nature of atoms has changed. Electrons are now pictured as vibrating with certain wavelengths, which can make standing waves only at certain distances from the nucleus. Thus, the model of the atom changed from one that views electrons as solid particles to one that views them as vibrations.

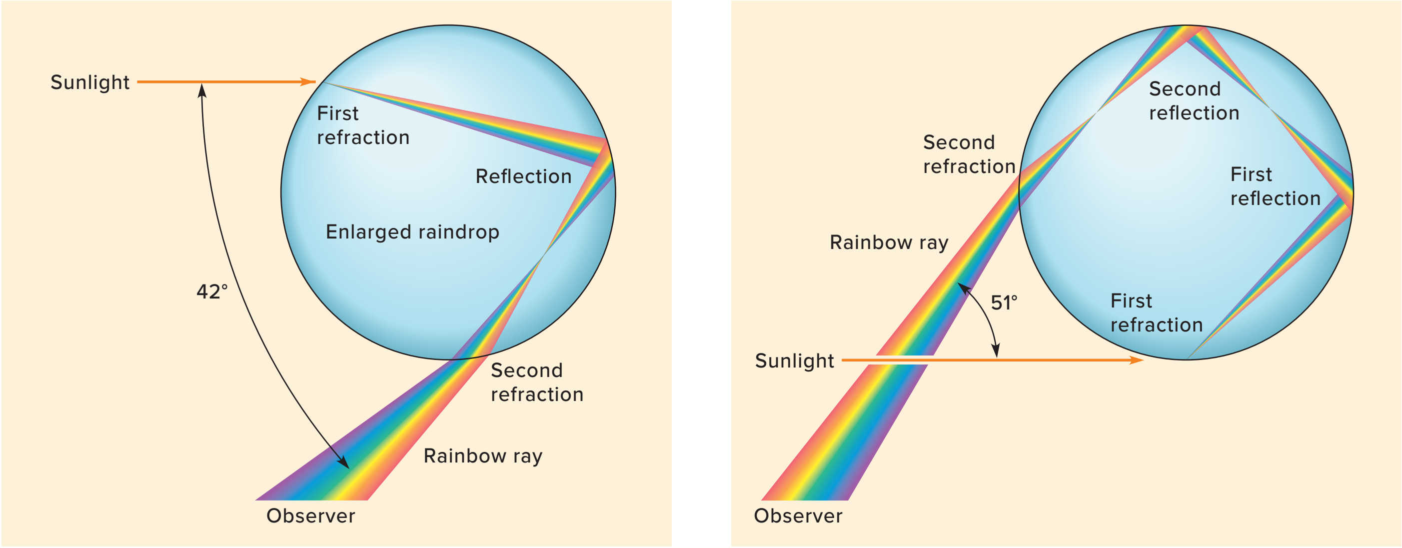
The most recently developed scientific theory was refined and expanded during the 1970s. This theory concerns the surface of Earth, and it has changed our model of what Earth is like. At first, the basic idea of today's accepted theory was pure and simple conjecture. The term *conjecture* usually means an explanation or idea based on speculation, or one based on trivial grounds without any real evidence. Scientists would look at a map of Africa and South America, for example, and mull over how the two continents look like pieces of a picture puzzle that had moved apart (Figure 1.16). Any talk of moving continents was considered conjecture, because it was not based on anything acceptable as real evidence.

Many years after the early musings about moving continents, evidence was collected from deep-sea drilling rigs that the ocean floor becomes progressively older toward the African and South American continents. This was good enough evidence to establish the "seafloor spreading hypothesis" that described the two continents moving apart.

If a hypothesis survives much experimental testing and leads, in turn, to the design of new experiments with the generation of new hypotheses that can be tested, you now have a working *theory*. A **theory** is defined as a broad working hypothesis that is based on extensive experimental evidence. A scientific theory tells you *why* something happens. For example, the plate tectonic theory describes how the continents have moved apart, just as pieces of a picture puzzle do. Is this the same idea that was once considered conjecture? Sort of, but this time it is supported by experimental evidence.

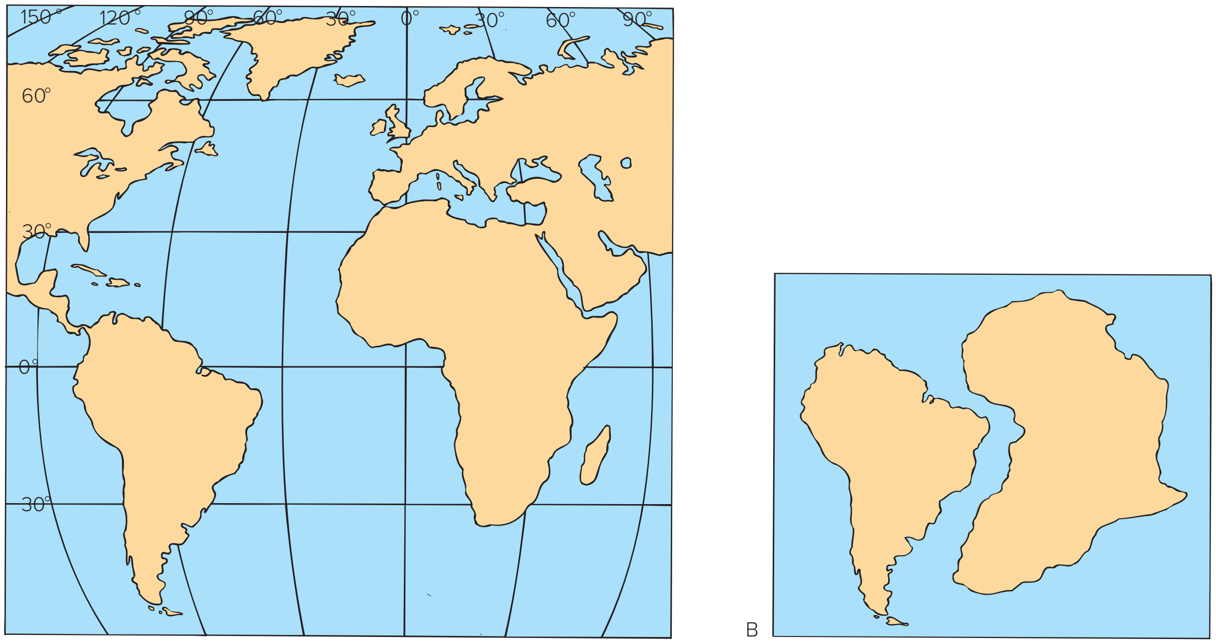
The term *scientific theory* is reserved for historic schemes of thought that have survived the test of detailed examination for long periods of time. The *atomic theory,* for example, was developed in the late 1800s and has been the subject of extensive investigation and experimentation over the last century. The atomic theory and other scientific theories form the framework of scientific thought and experimentation today. Scientific theories point to new ideas about the behavior of nature, and these ideas result in more experiments, more data to collect, and more explanations to develop. All of this may lead to a slight modification of an existing theory, a major modification, or perhaps the creation of an entirely new theory. These activities are all part of the continuing attempt to satisfy our curiosity about nature.

A



B

FIGURE 1.15 A model helps you visualize something that cannot be observed. You cannot observe what is making a double rainbow, for example, but models of light entering the upper and lower surfaces of a raindrop help you visualize what is happening. The drawings in *B* serve as a model that explains how a double rainbow is produced (also see "The Rainbow" in chapter 7). A: tropicalpix/E+/Getty Images



A B

FIGURE 1.16 (*A*) Normal position of the continents on a world map. (*B*) A sketch of South America and Africa, suggesting that they once might have been joined together and subsequently separated by continental drift.

SUMMARY

Physical science is a search for order in our physical surroundings. People have *concepts,* or mental images, about material *objects* and intangible *events* in their surroundings. Concepts are used for thinking and communicating. Concepts are based on *properties,* or attributes that describe a thing or event. Every property implies a *referent* that describes the property. Referents are not always explicit, and most communications require assumptions. Measurement brings precision to descriptions by using numbers and standard units for referents to communicate "exactly how much of exactly what."

Measurement is a process that uses a well-defined and agreed-upon *referent* to describe a *standard unit*. The unit is compared to the property being defined by an operation that determines the *value* of the unit by *counting*. Measurements are always reported with a *number,* or value, and a *name* for the unit.

The two major *systems* of standard units are the *English system* and the *metric system*. The English system uses standard units that were originally based on human body parts, and the metric system uses standard units based on referents found in nature. The metric system also uses a system of prefixes to express larger or smaller amounts of units. The metric standard units for length, mass, and time are, respectively, the *meter, kilogram,* and *second*.

Measurement information used to describe something is called *data*. One way to extract meanings and generalizations from data is to use a *ratio,* a simplified relationship between two numbers. Density is a ratio of mass to volume, or $\rho = m/V$.

Symbols are used to represent *quantities*, or measured properties. Symbols are used in *equations*, which are shorthand statements that describe a relationship where the quantities (both number values and units) are identical on both sides of the equal sign. Equations are used to (1) *describe* a property, (2) *define* a concept, or (3) *describe* how *quantities change* together.

Quantities that can have different values at different times are called *variables*. Variables that increase or decrease together in the same ratio are said to be in *direct proportion*. If one variable increases while the other decreases in the same ratio, the variables are in *inverse proportion*. Proportionality statements are not necessarily equations. A *proportionality constant* can be used to make such a statement into an equation. Proportionality constants might have numerical value only, without units, or they might have both value and units.

Modern science began about three hundred years ago during the time of Galileo and Newton. Since that time, *scientific investigation* has been used to provide *experimental evidence* about nature. *Methods* used to conduct scientific investigations can be generalized as *collecting observations, developing explanations,* and *testing explanations*.

A *hypothesis* is a tentative explanation that is accepted or rejected based on experimental data. Experimental data can come from *observations* or from a *controlled experiment*. The controlled experiment compares two situations that have all the influencing factors identical except one. The single influencing variable being tested is called the *experimental variable*, and the group of variables that form the basis of comparison is called the *control group*.

An accepted hypothesis may result in a *principle,* an explanation concerned with a specific range of phenomena, or a *scientific law,* an explanation concerned with important, wider-ranging phenomena. Laws are sometimes identified with the name of a scientist and can be expressed verbally, with an equation, or with a graph.

A *model* is used to help us understand something that cannot be observed directly, explaining the unknown in terms of things already understood. Physical models, mental models, and equations are all examples of models that explain how nature behaves. A *theory* is a broad, detailed explanation that guides development and interpretations of experiments in a field of study.

SUMMARY OF EQUATIONS

1.1

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

$$\rho = \frac{m}{V}$$

KEY TERMS

area (p. 7)
controlled experiment (p. 15)
data (p. 7)
density (p. 8)
direct proportion (p. 10)
English system (p. 4)
equation (p. 10)
experiment (p. 14)
fundamental properties (p. 5)
hypothesis (p. 14)
inverse proportion (p. 10)
kilogram (p. 5)
liter (p. 6)
measurement (p. 4)
meter (p. 5)
metric system (p. 5)
model (p. 17)
numerical constant (p. 11)
properties (p. 3)
proportionality constant (p. 10)
quantities (p. 10)
ratio (p. 7)
referent (p. 3)
scientific law (p. 16)
scientific principle (p. 17)
second (p. 6)
standard unit (p. 4)
theory (p. 17)
unit (p. 4)
variable (p. 10)
volume (p. 7)

APPLYING THE CONCEPTS

1. A generalized mental image of an object is a (an)
a. definition.
b. impression.
c. concept.
d. mental picture.

2. Which of the following is the best example of the use of a referent?
a. A red bicycle
b. Big as a dump truck
c. The planet Mars
d. Your textbook

3. A well-defined and agreed-upon referent used as a standard in all systems of measurement is called a
a. yardstick.
b. unit.
c. quantity.
d. fundamental.

4. The system of measurement based on referents in nature, but not with respect to human body parts, is the
a. natural system.
b. English system.
c. metric system.
d. American system.

5. A process of comparing a property to a well-defined and agreed-upon referent is called a
a. measurement.
b. referral.
c. magnitude.
d. comparison.

6. One of the following is ***not*** considered to be a fundamental property:
a. weight.
b. length.
c. time.
d. charge.

7. How much space something occupies is described by its
a. mass.
b. volume.
c. density.
d. weight.

8. The relationship between two numbers that is usually obtained by dividing one number by the other is called a (an)
a. ratio.
b. divided size.
c. number tree.
d. equation.

9. The ratio of mass per volume of a substance is called its
a. weight.
b. weight-volume.
c. mass-volume.
d. density.

10. After identifying the appropriate equation, the next step in correctly solving a problem is to
a. substitute known quantities for symbols.
b. solve the equation for the variable in question.
c. separate the number and units.
d. convert all quantities to metric units.

11. Suppose a problem situation describes a speed in km/h and a length in m. What conversion should you do before substituting quantities for symbols? Convert
a. km/h to km/s.
b. m to km.
c. km/h to m/s.
d. In this situation, no conversions should be made.

12. An equation describes a relationship where
a. the numbers and units on both sides are proportional but not equal.
b. the numbers on both sides are equal but not the units.
c. the units on both sides are equal but not the numbers.
d. the numbers and units on both sides are equal.

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13. The equation $\rho = \frac{m}{V}$ is a statement that
a. describes a property.
b. defines how variables can change.
c. describes how properties change.
d. identifies the proportionality constant.

14. Measurement information that is used to describe something is called
a. referents.
b. properties.
c. data.
d. a scientific investigation.

15. If you consider a very small portion of a material that is the same throughout, the density of the small sample will be
a. much less.
b. slightly less.
c. the same.
d. greater.

16. The symbol Δ has a meaning of
a. "is proportional to."
b. "the change in."
c. "therefore."
d. "however."

17. A model is
a. a physical copy of an object or system made at a smaller scale.
b. a sketch of something complex used to solve problems.
c. an interpretation of a theory by use of an equation.
d. All of the above are models.

18. The use of a referent in describing a property always implies
a. a measurement.
b. naturally occurring concepts.
c. a comparison with a similar property of another object.
d. that people have the same understanding of concepts.

19. A 5 km span is the same as how many meters?
a. 0.005 m
b. 0.05 m
c. 500 m
d. 5,000 m

20. One-half liter of water is the same volume as
a. 5,000 mL.
b. 0.5 cc.
c. 500 cm^3.
d. 5 dm^3.

21. Which of the following is ***not*** a measurement?
a. 24°C
b. 65 mph
c. 120
d. 0.50 ppm

22. What happens to the surface-area-to-volume ratio as the volume of a cube becomes larger?
a. It remains the same.
b. It increases.
c. It decreases.
d. The answer varies.

23. If one variable increases in value while a second, related variable decreases in value, the relationship is said to be
a. direct.
b. inverse.
c. square.
d. inverse square.

24. What is needed to change a proportionality statement into an equation?
a. Include a proportionality constant.
b. Divide by an unknown to move the symbol to the left side of the equal symbol.
c. Add units to one side to make units equal.
d. Add numbers to one side to make both sides equal.

25. A proportionality constant
a. always has a unit.
b. never has a unit.
c. might or might not have a unit.

26. A scientific investigation provides understanding through
a. explanations based on logical thinking processes alone.
b. experimental evidence.
c. reasoned explanations based on observations.
d. diligent obeying of scientific laws.

27. Statements describing how nature is observed to behave consistently time after time are called scientific
a. theories.
b. laws.
c. models.
d. hypotheses.

28. A controlled experiment comparing two situations has all identical influencing factors except the
a. experimental variable.
b. control variable.
c. inverse variable.
d. direct variable.

29. In general, scientific investigations have which activities in common?
a. State problem, gather data, make hypothesis, test, make conclusion.
b. Collect observations, develop explanations, test explanations.
c. Observe nature, reason an explanation for what is observed.
d. Observe nature, collect data, modify data to fit scientific model.

30. Quantities, or measured properties, that are capable of changing values are called
a. data.
b. variables.
c. proportionality constants.
d. dimensionless constants.

31. A proportional relationship that is represented by the symbols $a \propto 1/b$ represents which of the following relationships?
a. direct proportion
b. inverse proportion
c. direct square proportion
d. inverse square proportion

32. A hypothesis concerned with a specific phenomenon is found to be acceptable through many experiments over a long period of time. This hypothesis usually becomes known as a
a. scientific law.
b. scientific principle.
c. theory.
d. model.

33. A scientific law can be expressed as
- **a.** a written concept.
- **b.** an equation.
- **c.** a graph.
- **d.** all of the above.

34. The symbol $\propto$ has a meaning of
- **a.** "almost infinity."
- **b.** "the change in."
- **c.** "is proportional to."
- **d.** "therefore."

35. Which of the following symbols represents a measured property of the compactness of matter?
- **a.** m
- **b.** ρ
- **c.** V
- **d.** Δ

36. A candle with a certain weight melts in an oven, and the resulting weight of the wax is
- **a.** less.
- **b.** the same.
- **c.** greater.
- **d.** The answer varies.

37. An ice cube with a certain volume melts, and the resulting volume of water is
- **a.** less.
- **b.** the same.
- **c.** greater.
- **d.** The answer varies.

38. Compare the density of ice to the density of water. The density of ice is
- **a.** less.
- **b.** the same.
- **c.** greater.
- **d.** The answer varies.

39. A beverage glass is filled to the brim with ice-cold water (0°C) and ice cubes. Some of the ice cubes are floating above the water level. When the ice melts, the water in the glass will
- **a.** spill over the brim.
- **b.** stay at the same level.
- **c.** be less full than before the ice melted.

40. What is the proportional relationship between the volume of juice in a cup and the time the juice dispenser has been running?
- **a.** direct
- **b.** inverse
- **c.** square
- **d.** inverse square

41. What is the proportional relationship between the number of cookies in the cookie jar and the time you have been eating the cookies?
- **a.** direct
- **b.** inverse
- **c.** square
- **d.** inverse square

42. A movie projector makes a 1 m by 1 m image when projecting 1 m from a screen, a 2 m by 2 m image when projecting 2 m from the screen, and a 3 m by 3 m image when projecting 3 m from the screen. What is the proportional relationship between the distance from the screen and the area of the image?
- **a.** direct
- **b.** inverse
- **c.** square
- **d.** inverse square

43. A movie projector makes a 1 m by 1 m image when projecting 1 m from a screen, a 2 m by 2 m image when projecting 2 m from the screen, and a 3 m by 3 m image when projecting 3 m from the screen. What is the proportional relationship between the distance from the screen and the intensity of the light falling on the screen?
- **a.** direct
- **b.** inverse
- **c.** square
- **d.** inverse square

44. According to the scientific method, what needs to be done to move beyond conjecture or simple hypotheses in a person's understanding of his or her physical surroundings?
- **a.** Make an educated guess.
- **b.** Conduct a controlled experiment.
- **c.** Find an understood model with answers.
- **d.** Search for answers on the Internet.

Answers

1. c **2.** b **3.** b **4.** c **5.** a **6.** a **7.** b **8.** a **9.** d **10.** b **11.** c **12.** d **13.** a **14.** c **15.** c **16.** b **17.** d **18.** c **19.** d **20.** c **21.** c **22.** c **23.** b **24.** a **25.** c **26.** b **27.** b **28.** a **29.** b **30.** b **31.** b **32.** a **33.** d **34.** c **35.** b **36.** b **37.** a **38.** a **39.** b **40.** a **41.** b **42.** c **43.** d **44.** b

QUESTIONS FOR THOUGHT

1. What is a concept?
2. What are two components of a measurement statement? What does each component tell you?
3. Other than familiarity, what are the advantages of the English system of measurement?
4. Define the metric standard units for length, mass, and time.
5. Does the density of a liquid change with the shape of a container? Explain.
6. Does a flattened pancake of clay have the same density as the same clay rolled into a ball? Explain.
7. What is an equation? How are equations used in the physical sciences?
8. Compare and contrast a scientific principle and a scientific law.
9. What is a model? How are models used?
10. Are all theories always completely accepted or completely rejected? Explain.

FOR FURTHER ANALYSIS

1. Select a statement that you feel might represent pseudoscience. Write an essay supporting *and* refuting your selection, noting facts that support one position or the other.
2. Evaluate the statement that science cannot solve human-produced problems such as pollution. What does it mean to say pollution is caused by humans and can only be solved by humans? Provide evidence that supports your position.
3. Make an experimental evaluation of what happens to the density of a substance at larger and larger volumes.

4. If your wage were dependent on your work-time squared, how would it affect your pay if you doubled your hours?
5. Merriam-Webster's 11th *Collegiate Dictionary* defines *science,* in part, as "knowledge or a system of knowledge covering general truths or the operation of general laws especially as obtained and tested through scientific method." How would you define science?
6. Are there any ways in which scientific methods differ from commonsense methods of reasoning?
7. The United States is the only country in the world that does not use the metric system of measurement. With this understanding, make a list of advantages and disadvantages for adopting the metric system in the United States.

INVITATION TO INQUIRY

Paper Helicopters

Construct paper helicopters and study the effects that different variables have on their flight. After considering the size you wish to test, copy the patterns shown in Figure 1.17 on a sheet of notebook paper. Note that solid lines are to be cut and dashed lines are to be folded. Make three scissor cuts on the solid lines. Fold A toward you and B away from you to form the wings. Then fold C and D inward to overlap, forming the body. Finally, fold up the bottom on the dashed line and hold it together with a paper clip. Your finished product should look like the helicopter in Figure 1.17. Try a preliminary flight test by standing on a chair or stairs and dropping it.

Decide what variables you would like to study to find out how they influence the total flight time. Consider how you will hold everything else constant while changing one variable at a time. You can change the wing area by making new helicopters with more or less area in the A and B flaps. You can change the weight by adding more paper clips. Study these and other variables to find out who can design a helicopter that will remain in the air the longest. Who can design a helicopter that is most accurate in hitting a target?

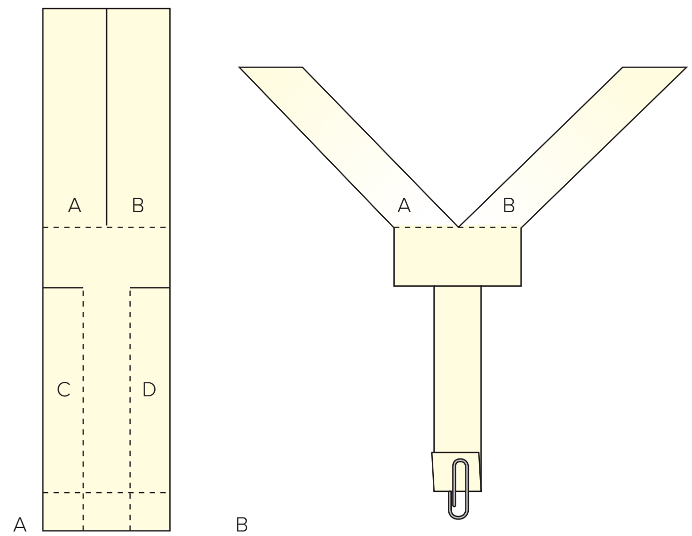


FIGURE 1.17 Pattern for a paper helicopter.

PARALLEL EXERCISES

The exercises in groups A and B cover the same concepts. Solutions to group A exercises are located in appendix E.
Note: *You will need to refer to* Table 1.3 *to complete some of the following exercises.*

Group A

1. What is your height in meters? In centimeters?
2. What is the density of mercury if 20.0 cm^3 has a mass of 272 g?
3. What is the mass of a 10.0 cm^3 cube of lead?
4. What is the volume of a rock with a density of 3.00 g/cm^3 and a mass of 600 g?
5. If you have 34.0 g of a 50.0 cm^3 volume of one of the substances listed in Table 1.3, which one is it?
6. What is the mass of water in a 40 L aquarium?
7. A 2.1 kg pile of aluminum cans is melted, then cooled into a solid cube. What is the volume of the cube?
8. A cubic box contains 1,000 g of water. What is the length of one side of the box in meters? Explain your reasoning.
9. A loaf of bread (volume 3,000 cm^3) with a density of 0.2 g/cm^3 is crushed in the bottom of a grocery bag into a volume of 1,500 cm^3. What is the density of the mashed bread?
10. According to Table 1.3, what volume of copper would be needed to balance a 1.00 cm^3 sample of lead on a two-pan laboratory balance?

Group B

1. What is your mass in kilograms? In grams?
2. What is the density of iron if 5.0 cm^3 has a mass of 39.5 g?
3. What is the mass of a 10.0 cm^3 cube of copper?
4. If ice has a density of 0.92 g/cm^3, what is the volume of 5,000 g of ice?
5. If you have 51.5 g of a 50.0 cm^3 volume of one of the substances listed in Table 1.3, which one is it?
6. What is the mass of gasoline ($\rho = 0.680$ g/cm^3) in a 94.6 L gasoline tank?
7. What is the volume of a 2.00 kg pile of iron cans that are melted, then cooled into a solid cube?
8. A cubic tank holds 1,000.0 kg of water. What are the dimensions of the tank in meters? Explain your reasoning.
9. A hot dog bun (volume 240 cm^3) with a density of 0.15 g/cm^3 is crushed in a picnic cooler into a volume of 195 cm^3. What is the new density of the bun?
10. According to Table 1.3, what volume of iron would be needed to balance a 1.00 cm^3 sample of lead on a two-pan laboratory balance?

PHYSICS

2

Motion

Information about the mass of a hot air balloon and forces on it will enable you to predict if it is going to move up, down, or drift across the surface. This chapter is about such relationships among force, mass, and changes in motion.
Patrick Foto/Shutterstock

CORE CONCEPT

A net force is required for any change in a state of motion.

OUTLINE

Forces
Inertia is the tendency of an object to remain in unchanging motion when the net force is zero.

Newton's First Law of Motion
Every object retains its state of rest or straight-line motion unless acted upon by an unbalanced force.

Newton's Third Law of Motion
A single force does not exist by itself; there is always a matched and opposite force that occurs at the same time.

Falling Objects
The force of gravity uniformly accelerates falling objects.

Newton's Second Law of Motion
The acceleration of an object depends on the net force applied and the mass of the object.

Newton's Law of Gravitation
All objects in the universe are attracted to all other objects in the universe.

OVERVIEW

In chapter 1, you learned some "tools and rules" and some techniques for finding order in your physical surroundings. Order is often found in the form of patterns, or relationships between quantities that are expressed as equations. Recall that equations can be used to (1) describe properties, (2) define concepts, and (3) describe how quantities change relative to one another. In all three uses, patterns are quantified, conceptualized, and used to gain a general understanding about what is happening in nature.

In the study of physical science, certain parts of nature are often considered and studied together for convenience. One of the more obvious groupings involves *movement*. Most objects around you spend a great deal of time sitting quietly without motion. Buildings, rocks, utility poles, and trees rarely, if ever, move from one place to another. Even things that do move from time to time sit still for a great deal of time. This includes you, bicycles, and surfboards (Figure 2.1). On the other hand, the Sun, the Moon, and starry heavens seem to always move, never standing still. Why do things stand still? Why do things move?

Questions about motion have captured the attention of people for thousands of years. But the ancient people answered questions about motion with stories of mysticism and spirits that lived in objects. It was during the classic Greek culture, between 600 B.C. and 300 B.C., that people began to look beyond magic and spirits. One particular Greek philosopher, Aristotle, wrote a theory about the universe that offered not only explanations about things such as motion but also a sense of beauty, order, and perfection. The theory seemed to fit with other ideas that people had and was held to be correct for nearly two thousand years after it was written. It was not until the work of Galileo and Newton during the 1600s that a new, correct understanding about motion was developed. The development of ideas about motion is an amazing and absorbing story. You will learn in this chapter how to describe and use some properties of motion. This will provide some basic understandings about motion and will be very helpful in understanding some important aspects of astronomy and the earth sciences, as well as the movement of living things.

2.1 DESCRIBING MOTION

Motion is one of the more common events in your surroundings. You can see motion in natural events such as clouds moving, rain and snow falling, and streams of water moving, all in a never-ending cycle. Motion can also be seen in the activities of people who walk, jog, or drive various machines from place to place. Motion is so common that you would think everyone would intuitively understand the concepts of motion, but history indicates that it was only during the past three hundred years or so that people began to understand motion correctly. Perhaps the correct concepts are subtle and contrary to common sense, requiring a search for simple, clear concepts in an otherwise complex situation. The process of finding such order in a multitude of sensory impressions by taking measurable data and then inventing a concept to describe what is happening is the activity called *science*. We will now apply this process to motion.

What is motion? Consider a ball that you notice one morning in the middle of a lawn. Later in the afternoon, you notice that the ball is at the edge of the lawn, against a fence, and you wonder if the wind or some person moved the ball. You do not know if the wind blew it at a steady rate, if many gusts of wind moved it, or even if some children kicked it all over the yard. All you know for sure is that the ball has been moved because it is

FIGURE 2.1 The motion of this windsurfer, and of other moving objects, can be described in terms of the distance covered during a certain time period. Ben Welsh/Design Pics

in a different position after some time passed. These are the two important aspects of motion: (1) a change of position and (2) the passage of time.

If you did happen to see the ball rolling across the lawn in the wind, you would see more than the ball at just two locations. You would see the ball moving continuously. You could consider, however, the ball in continuous motion to be a series of individual locations with very small time intervals. In this sense, motion is characterized by just two quantities: the total change in position and amount of time the movement takes.

The easiest way to describe the motion of an object is by comparing it to another object that is not moving—a stationary object "at rest." Imagine that you are traveling in an automobile with another person. You know that you are moving across the land outside the car since your location on the highway changes from one moment to another. Observing your fellow passenger, however, reveals no change of position. You are in motion relative to the highway outside the car. You are not in motion relative to your fellow passenger. Your motion, and the motion of any other object or body, is the process of a change in position *relative* to some reference object or location. Thus, *motion* can be defined as the act or process of changing position relative to some reference during a period of time.

2.2 MEASURING MOTION

You have learned that objects can be described by measuring certain fundamental properties such as mass and length. Since motion involves (1) a change of *position* and (2) the passage of *time,* the motion of objects can be described by using combinations of the fundamental properties of length and time. These combinations of measurement describe three properties of motion: *speed, velocity,* and *acceleration*.

SPEED

Suppose you are in a car that is moving over a straight road. How could you describe your motion? You need at least two measurements: (1) the distance you have traveled and (2) the time that has elapsed while you covered this distance. Such a distance and time can be expressed as a ratio that describes your motion. This ratio is a property of motion called **speed,** which is a measure of how fast you are moving. *Speed* is defined as distance per unit of time, or

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

The units used to describe speed are usually miles/hour (mi/h), kilometers/hour (km/h), or meters/second (m/s).

Let's go back to your car that is moving over a straight highway and imagine you are driving to cover equal distances in equal periods of time. If you use a stopwatch to measure the time required to cover the distance between highway mile markers (those little signs with numbers along major highways), the time intervals will all be equal. You might find, for example, that one minute lapses between each mile marker. Such a uniform straight-line motion that covers equal distances in equal periods of time is the simplest kind of motion.

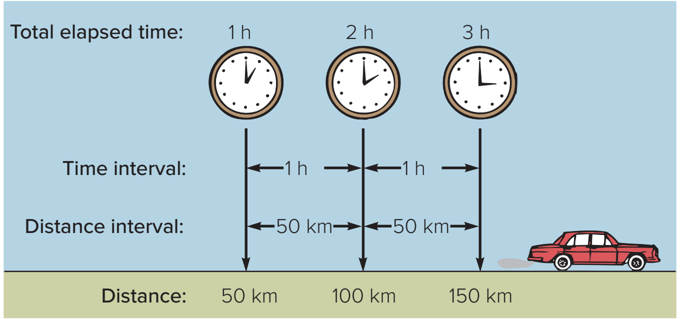


FIGURE 2.2 If you know the value of any two of the three variables of distance, time, and speed, you can find the third. What is the average speed of this car? Two ways of finding the answer are in Figure 2.3.

If your car is neither speeding up nor slowing down, it has a *constant speed* (Figure 2.2). This means that the car is moving over equal distances in equal periods of time.

It is usually difficult to maintain a constant speed while driving a car. Other cars and distractions such as interesting scenery cause you to reduce your speed. At other times you increase your speed. If you calculate your speed over an entire trip, you are considering a large distance between two places and the total time that elapsed. The increases and decreases in speed would be averaged. Therefore, most speed calculations are for an *average speed*. The speed at any specific instant is called the *instantaneous speed*. To calculate the instantaneous speed, you would need to consider a very short time interval—one that approaches zero. An easier way would be to use the speedometer, which shows the speed at any instant.

Constant, instantaneous, or average speeds can be measured with any distance and time units. Common units in the English system are miles/hour and feet/second. Metric units for speed are commonly kilometers/hour and meters/second. The ratio of any distance to time is usually read as distance per time, such as miles per hour. The *per* means "for each."

It is easier to study the relationships between quantities if you use symbols instead of writing out the whole word. The letter v can be used to stand for speed, the letter d can be used to stand for distance, and the letter t to stand for time. A bar over the v ($\bar{v}$) is a symbol that means average (it is read "v-bar" or "v-average"). The relationship between average speed, distance, and time is therefore

$$\bar{v} = \frac{d}{t}$$

equation 2.1

This is one of the three types of equations that were discussed on page 10, and in this case, the equation defines a motion property. You can use this relationship to find average

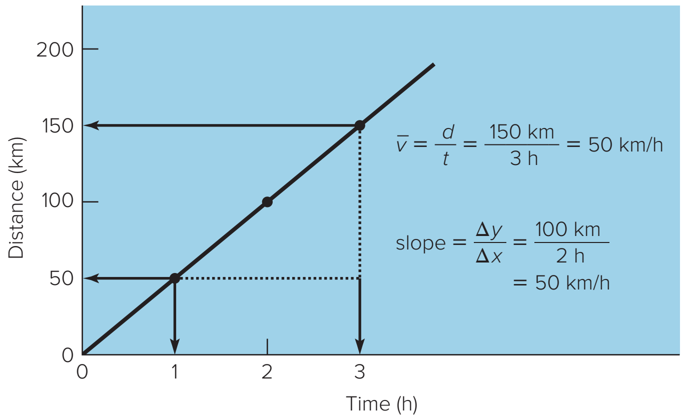


FIGURE 2.3 Speed is distance per unit of time, which can be calculated from the equation or by finding the slope of a distance-versus-time graph. This shows both ways of finding the speed of the car shown in Figure 2.2.

speed. For example, suppose a car travels 150 km in 3 h. What was the average speed? Since $d = 150$ km and $t = 3$ h, then

$$\bar{v} = \frac{150\text{ km}}{3\text{ h}}$$
$$= 50\frac{\text{km}}{\text{h}}$$

As with other equations, you can mathematically solve the equation for any term as long as two variables are known (Figure 2.3). For example, suppose you know the speed and the time but want to find the distance traveled. You can solve this by first writing the relationship

$$\bar{v} = \frac{d}{t}$$

and then multiplying both sides of the equation by t (to get d on one side by itself),

$$(\bar{v})(t) = \frac{(d)(\cancel{t})}{\cancel{t}}$$

and the t's on the right cancel, leaving

$$\bar{v}t = d \qquad \text{or} \qquad d = \bar{v}t$$

If the $\bar{v}$ is 50 km/h and the time traveled is 2 h, then

$$d = \left(50\frac{\text{km}}{\text{h}}\right)(2\text{h})$$
$$= (50)(2)\left(\frac{\text{km}}{\text{h}}\right)(\text{h})$$
$$= 100\frac{(\text{km})(\cancel{\text{h}})}{\cancel{\text{h}}}$$
$$= 100\text{ km}$$

Notice how both the numerical values and the units were treated mathematically. See "How to Solve Problems" in chapter 1 for more information.

EXAMPLE 2.1

The driver of a car moving at 72.0 km/h drops a road map on the floor. It takes him 3.00 seconds to locate and pick up the map. How far did he travel during this time?

SOLUTION

The car has a speed of 72.0 km/h and the time factor is 3.00 s, so km/h must be converted to m/s. From inside the front cover of this book, the conversion factor is 1 km/h = 0.2778 m/s, so

$$\bar{v} = \frac{0.2778\frac{\text{m}}{\text{s}}}{\frac{\text{km}}{\text{h}}} \times 72.0\frac{\text{km}}{\text{h}}$$
$$= (0.2778)(72.0)\frac{\text{m}}{\text{s}} \times \frac{\text{h}}{\text{km}} \times \frac{\text{km}}{\text{h}}$$
$$= 20.0\frac{\text{m}}{\text{s}}$$

The relationship between the three variables, $\bar{v}$, t, and d, is found in equation 2.1: $\bar{v} = d/t$.

$\bar{v} = 20.0\frac{\text{m}}{\text{s}}$ $\qquad$ $\bar{v} = \frac{d}{t}$

$t = 3.00$ s $\qquad$ $\bar{v}t = \frac{d\cancel{t}}{\cancel{t}}$

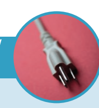
$d = ?$ $\qquad$ $d = \bar{v}t$

$$= \left(20.0\frac{\text{m}}{\text{s}}\right)(3.00\text{ s})$$
$$= (20.0)(3.00)\frac{\text{m}}{\text{s}} \times \frac{\text{s}}{1}$$
$$= \boxed{60.0\text{ m}}$$

EXAMPLE 2.2

A bicycle has an average speed of 8.00 km/h. How far will it travel in 10.0 seconds? (Answer: 22.2 m)

CONCEPTS *Applied*



Style Speeds

Observe how many different styles of walking you can identify in students walking across the campus. Identify each style with a descriptive word or phrase.

Is there any relationship between any particular style of walking and the speed of walking? You could find the speed of walking by measuring a distance, such as the distance between two trees, then measuring the time required for a student to walk the distance. Find the average speed for each identified style of walking by averaging the walking speeds of ten people.

Report any relationships you find between styles of walking and the average speed of people with each style. Include any problems you found in measuring, collecting data, and reaching conclusions.

CONCEPTS*Applied*

How Fast Is a Stream?

A stream is a moving body of water. How could you measure the speed of a stream? Would timing how long it takes a floating leaf to move a measured distance help?

What kind of relationship, if any, would you predict for the speed of a stream and a recent rainfall? Would you predict a direct relationship? Make some measurements of stream speeds and compare your findings to recent rainfall amounts.

VELOCITY

In day-to-day speech, the word *velocity* is sometimes used interchangeably with the word speed, but there is an important difference. **Velocity** describes the *speed and direction* of a moving object. For example, a speed might be described as 60 km/h, but it includes no specific direction of movement. A velocity might be described as 60 km/h to the west.

To produce a change in velocity, either the speed or the direction can be changed (or both are changed). A satellite moving with a constant speed in a circular orbit around Earth does not have a constant velocity since its direction of movement is constantly changing. Velocity can be represented graphically with arrows. The lengths of the arrows are proportional to the magnitude, and the arrowheads indicate the direction (Figure 2.4).

ACCELERATION

Motion can be changed in three different ways: (1) by changing the speed, (2) by changing the direction of travel, or

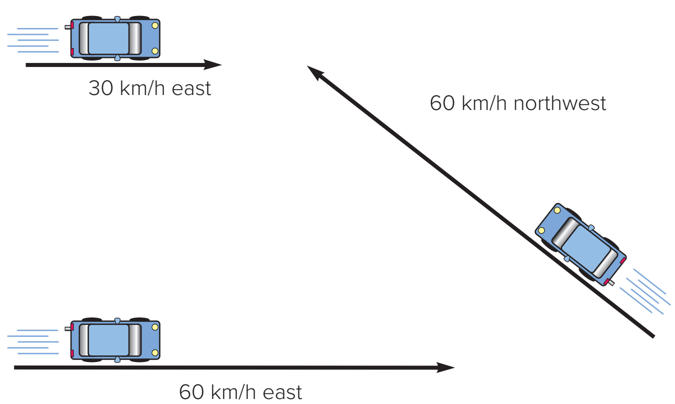


FIGURE 2.4 Here are three different velocities represented by three different arrows. The length of each arrow is proportional to the speed, and the arrowhead shows the direction of travel.

SCIENCE *Sketch*

Draw and label three additional cars to those shown Figure 2.4 to represent (i) a negative velocity; (ii) a north velocity; and (iii) a 50% velocity.

(3) combining both of these by changing both the speed and the direction of travel at the same time. Since velocity describes both the speed and the direction of travel, any of these three changes will result in a change of velocity. You need at least one additional measurement to describe a change of motion, which is how much time elapsed while the change was taking place. The change of velocity and time can be combined to define the *rate* at which the motion was changed. This rate is called **acceleration.** *Acceleration* is defined as a change of velocity per unit time, or

$$\text{acceleration} = \frac{\text{change of velocity}}{\text{time elapsed}}$$

Another way of saying "change in velocity" is the final velocity minus the initial velocity, so the relationship can also be written as

$$\text{acceleration} = \frac{\text{final velocity} - \text{initial velocity}}{\text{time elapsed}}$$

Acceleration due to a change in speed only can be calculated as follows: Consider a car that is moving with a constant, straight-line velocity of 60 km/h when the driver accelerates to 80 km/h. Suppose it takes 4 s to increase the velocity of 60 km/h to 80 km/h. The change in velocity is therefore 80 km/h minus 60 km/h, or 20 km/h. The acceleration was

$$\text{acceleration} = \frac{80\frac{\text{km}}{\text{h}} - 60\frac{\text{km}}{\text{h}}}{4\text{ s}}$$

$$= \frac{20\frac{\text{km}}{\text{h}}}{4\text{ s}}$$

$$= 5\frac{\text{km/h}}{\text{s}} \text{ or}$$

$$= 5\text{ km/h/s}$$

The average acceleration of the car was 5 km/h for each ("per") second. This is another way of saying that the velocity increases an average of 5 km/h in each second. The velocity of the car was 60 km/h when the acceleration began (initial velocity). At the end of 1 s, the velocity was 65 km/h. At the end of 2 s, it was 70 km/h; at the end of 3 s, 75 km/h; and at the end of 4 s (total time elapsed), the velocity was 80 km/h (final velocity). Note how fast the velocity is changing with time. In summary,

Start (initial velocity)	60 km/h
End of first second	65 km/h
End of second second	70 km/h
End of third second	75 km/h
End of fourth second (final velocity)	80 km/h

As you can see, acceleration is partially a description of how fast the speed is changing (Figure 2.5); in this case, it is increasing 5 km/h each second.

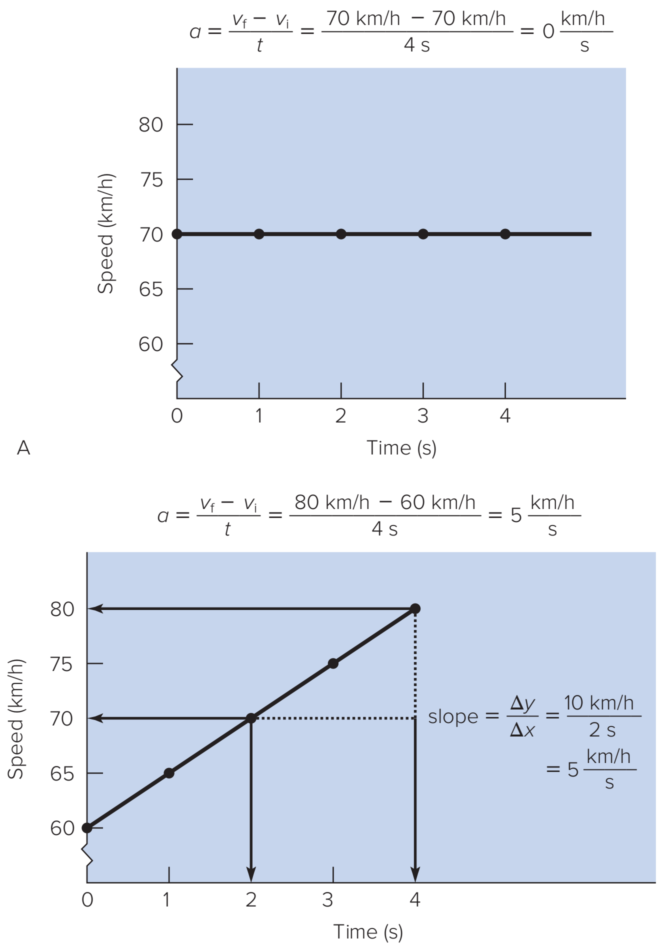


FIGURE 2.5 (*A*) This graph shows how the speed changes per unit of time while driving at a constant 70 km/h in a straight line. As you can see, the speed is constant, and for straight-line motion, the acceleration is 0. (*B*) This graph shows the speed increasing from 60 km/h to 80 km/h for 5 s. The acceleration, or change of velocity per unit of time, can be calculated either from the equation for acceleration or by calculating the slope of the straight-line graph. Both will tell you how fast the motion is changing with time.

Usually, you would want all the units to be the same, so you would convert km/h to m/s. A change in velocity of 5.0 km/h converts to 1.4 m/s, and the acceleration would be 1.4 m/s/s. The units m/s per s mean that change of velocity (1.4 m/s) is occurring every second. The combination m/s/s is rather cumbersome, so it is typically simplified to m/s^2.

The relationship among the quantities involved in acceleration can be represented with the symbols a for average acceleration, v_f for final velocity, v_i for initial velocity, and t for time. The relationship is

$$a = \frac{v_f - v_i}{t}$$

equation 2.2

As in other equations, any one of these quantities can be found if the others are known. For example, solving the equation for the final velocity, v_f, yields

$$v_f = at + v_i$$

Recall from chapter 1 that the symbol Δ means "the change in" a value. Therefore, equation 2.1 for speed could be written

$$\bar{v} = \frac{\Delta d}{t}$$

and equation 2.2 for acceleration could be written

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

This shows that both equations are a time rate of change. Speed is a time rate change of *distance.* Acceleration is a time rate change of *velocity.* The time rate of change of something is an important concept that you will meet again in chapter 3.

EXAMPLE 2.3

A bicycle moves from rest to 5 m/s in 5 s. What was the acceleration?

SOLUTION

$v_i = 0$ m/s

$v_f = 5$ m/s

$t = 5$ s

$a = ?$

$$a = \frac{v_f - v_i}{t} = \frac{5\ \text{m/s} - 0\ \text{m/s}}{5\ \text{s}} = \frac{5}{5}\frac{\text{m/s}}{\text{s}} = 1\left(\frac{\text{m}}{\text{s}}\right)\left(\frac{1}{\text{s}}\right) = \boxed{1\ \frac{\text{m}}{\text{s}^2}}$$

EXAMPLE 2.4

An automobile uniformly accelerates from rest at 5 m/s^2 for 6 s. What is the final velocity in m/s? (Answer: 30 m/s)

Other than speeding up an object's motion, there are other ways to accelerate an object. Your car's brakes, for example, can slow your car or bring it to a complete stop. This is *negative acceleration,* which is sometimes called *deceleration.* Both positive and negative accelerations can be felt by the passenger in a car. When you feel your body fight against the motion of your car, that's a good sign that an acceleration is happening. Another change in the motion of an object is a change of direction. You have certainly felt this type of acceleration as a passenger in a car. When the driver of a car accelerates the car by turning to the left, the

Science and Society

Transportation and the Environment

Environmental science is an interdisciplinary study of Earth's environment. The concern of this study is the overall problem of human degradation of the environment and remedies for that damage. As an example of an environmental topic of study, consider the damage that results from current human activities involving the use of transportation. Researchers estimate that overall transportation activities are responsible for about one-third of the total U.S. carbon emissions that are added to the air every day. Carbon emissions are a problem because they are directly harmful in the form of carbon monoxide. They are also indirectly harmful because of the contribution of carbon dioxide to possible global warming and the consequences of climate change.

Here is a list of things that people might do to reduce the amount of environmental damage from transportation:

A. Use a bike, carpool, walk, or take public transportation whenever possible.

B. Combine trips to the store, mall, and work, leaving the car parked whenever possible.

C. Purchase hybrid electric or fuel cell–powered cars or vehicles whenever possible.

D. Move to a planned community that makes the use of cars less necessary and less desirable.

QUESTIONS TO DISCUSS

Discuss with your group the following questions concerning connections between thought and feeling:

1. What are your positive or negative feelings associated with each item in the list?
2. Would your feelings be different if you had a better understanding of the global problem?
3. Do your feelings mean that you have reached a conclusion?
4. What new items could be added to the list?

passengers and objects in the vehicle have a tendency to lean to the right. Your automobile has three devices that could change the state of its motion. Your automobile therefore has three accelerators—the gas pedal (which can increase the magnitude of velocity), the brakes (which can decrease the magnitude of velocity), and the steering wheel (which can change the direction of the velocity). (See Figure 2.6.) The important thing to remember is that acceleration results from any *change* in the motion of an object.

The final velocity (v_f) and the initial velocity (v_i) are different variables than the average velocity ($\bar{v}$). You cannot use an initial or final velocity for an average velocity. You may, however, calculate an average velocity ($\bar{v}$) from the other two variables as long as the acceleration taking place between the initial and final velocities is uniform. An example of such a uniform change would be an automobile during a constant, straight-line acceleration. To find an average velocity *during* a uniform acceleration, you add the initial velocity and the final velocity and divide by 2. This averaging can be done for a uniform acceleration that is increasing the velocity or for one that is decreasing the velocity. In symbols,

$$\bar{v} = \frac{v_f + v_i}{2}$$

equation 2.3

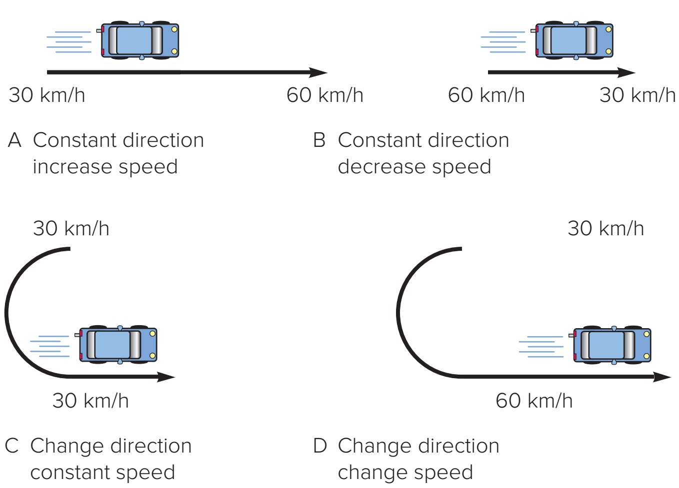


FIGURE 2.6 Four different ways (*A–D*) to accelerate a car.

EXAMPLE 2.5

An automobile moving at 25.0 m/s comes to a stop in 10.0 s when the driver slams on the brakes. How far did the car travel while stopping?

SOLUTION

The car has an initial velocity of 25.0 m/s (v_i) and the final velocity of 0 m/s (v_f) is implied. The time of 10.0 s (t) is given. The problem asked for the distance (d). The relationship given between $\bar{v}$, t, and d is given in equation 2.1, $\bar{v} = d/t$, which can be solved for d. The average velocity ($\overline{v}$), however, is not given but can be found from equation 2.3.

$$\overline{v} = \frac{v_f + v_i}{2} \qquad \overline{v} = \frac{d}{t} \quad \therefore \quad d = \overline{v} \cdot t$$

$v_i = 25.0$ m/s

$v_f = 0$ m/s

$t = 10.0$ s

$\overline{v} = ?$

$d = ?$

Since $\overline{v} = \dfrac{v_f + v_i}{2}$,

you can substitute $\left(\dfrac{v_f + v_i}{2}\right)$ for $\overline{v}$, and

$$d = \left(\frac{v_f + v_i}{2}\right)(t)$$

$$= \left(\frac{0\frac{\text{m}}{\text{s}} + 25.0\frac{\text{m}}{\text{s}}}{2}\right)(10.0 \text{ s})$$

$$= 12.5 \times 10.0 \frac{\text{m}}{\text{s}} \times \text{s}$$

$$= 125 \frac{\text{m} \cdot \cancel{\text{s}}}{\cancel{\text{s}}}$$

$$= \boxed{125 \text{ m}}$$

EXAMPLE 2.6

What was the deceleration of the automobile in example 2.5? (Answer: -2.50 m/s^2)

CONCEPTS *Applied*

Acceleration Patterns

Suppose the radiator in your car has a leak and drops of fluid fall constantly, one every second. What pattern will the drops make on the pavement when you accelerate the car from a stoplight? What pattern will they make when you drive at a constant speed? What pattern will you observe as the car comes to a stop? Use a marker to make dots on a sheet of paper that illustrate (1) acceleration, (2) constant speed, and (3) negative acceleration. Use words to describe the acceleration in each situation.

FORCES

A **force** is a push or a pull that is capable of changing the state of motion of an object. Consider, for example, the movement of a ship from the pushing of two tugboats (Figure 2.7). While each tugboat applies a force to the ship, the **net force** is the sum of all the forces acting on an object. Net force means "final," after the forces are added (Figure 2.8). The net force on the ship can be determined by adding the two tugboats' forces together. In the first case, the two tugboats are each applying a force of 1,000 units in the same direction; the net force is 2,000 units. What would the net force be if one of the tugboats applied more force, providing 3,000 units? The net force would be 1,000 units plus 3,000 units, for a total of 4,000 units. In the second case, the tugboats are applying the same amount of force in opposite directions, creating a net force of zero units. This might be important if the tugboats are tasked with holding the ship in place. In the final case, the tugboats are applying force in opposite directions with different strengths, resulting in a 1,000 units net force in one direction.

Determining the net force on an object can be accomplished with a few simple rules. When two forces act in the same direction, they can be simply added. When two parallel forces act in opposite directions, the net force is the difference between the two forces and is in the direction of the larger force. When two forces act neither in a way that is exactly together nor exactly opposite each other, the result will be like a new, different force having a new direction and strength. Forces have a strength and direction that can be represented by force arrows. The tail of the arrow is placed on the object that feels the force, and the arrowhead points in the direction in which the force is exerted. The length of the arrow is proportional to the strength of the force. The use of force arrows helps you visualize and understand all the forces and how they contribute to the net force.

There are four **fundamental forces** that cannot be explained in terms of any other force. They are gravitational, electromagnetic, weak, and the strong nuclear force. Gravitational forces act between objects in the Universe that have mass—between you and a person sitting next to you, between you and the Earth, between the Earth and the Sun, between the planets in the solar systems, between the stars in the Milky Way, and between the Milky Way and our closest galaxy neighbor, the Andromeda Galaxy. Rather than acting on objects that have mass, electromagnetic forces act between objects that are electrically charged, such as electrons and protons. Electromagnetic forces are responsible for the structure of atoms, chemical changes, and electricity and magnetism. The weak and strong forces act inside the nucleus of an atom, so they are not as easily observed at work as are gravitational and electromagnetic forces. The weak force is involved in nuclear reactions, while the strong nuclear force is involved in holding together the nuclei of atoms. While it goes unnoticed in everyday experiences, the strong nuclear force between particles inside a nucleus is about 10^2 times stronger than the electromagnetic force and about 10^{39} times stronger than the gravitational force! The four fundamental forces serve as the basic building blocks for every scientific explanation for everything that happens in the Universe.

FIGURE 2.7 The rate of movement and the direction of movement of this ship are determined by a combination of direction and size of force from each of the tugboats. In which direction are the two tugboats pushing? What evidence would indicate that one tugboat is pushing with a greater force? If the tugboat by the numbers is pushing with a greater force and the back tugboat is keeping the back of the ship from moving, what will happen? Bill W. Tillery

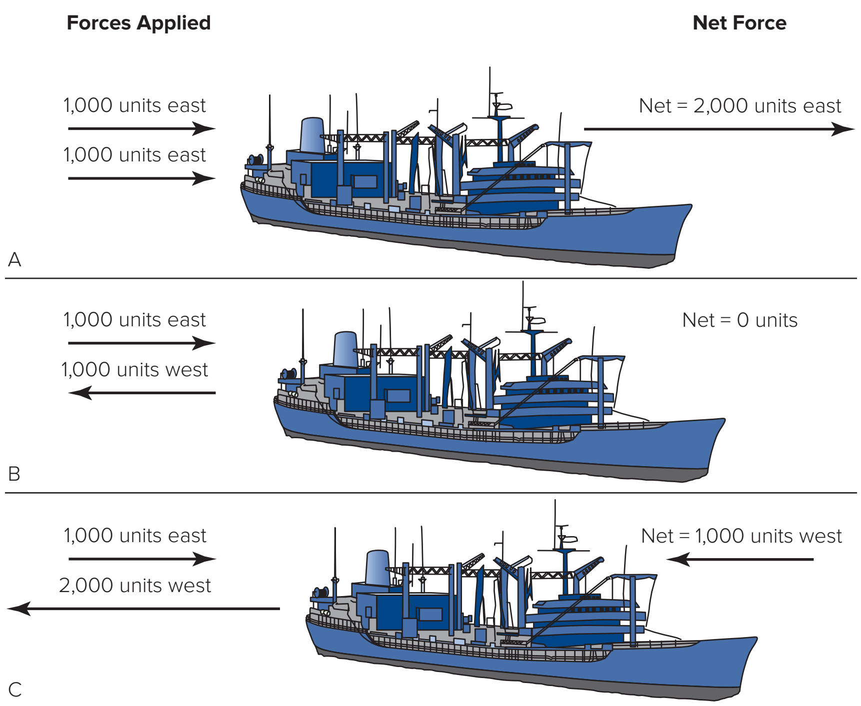


FIGURE 2.8 (*A*) When two parallel forces are acting on the ship in the same direction, the net force is the two forces added together. (*B*) When two forces are opposite and of equal size, the net force is zero. (*C*) When two parallel forces in opposite directions are not of equal size, the net force is the difference in the direction of the larger force.

2.3 HORIZONTAL MOTION ON LAND

The Greek philosopher Aristotle considered some of the first ideas about the causes of motion back in the fourth century B.C. Aristotle's approach was philosophical, rather than scientific, relying on observation and logic rather than testing. This led to some errors on his part, that were not refuted by anyone, as measurement and experimentation were not tools of the philosophers of the time. As a result, it would take about two thousand years before people began to correctly understand motion.

It is important not be too hard on Aristotle and his students, as everyday experience seems to indicate that some of Aristotle's ideas about motion are correct. For instance, Aristotle believed that objects must have a force constantly applied to them to keep them in motion. In everyday life, moving objects that are not pushed or pulled do come to rest in a short period of time. It does seem that an object keeps moving only if a force continues to push it. A moving automobile will slow and come to rest if you turn off the ignition. Likewise, a ball that you roll along the floor will slow until it comes to rest. Is the natural state of an object to be at rest, and is a force necessary to keep an object in motion? Virtually all people thought so until Galileo suggested (and published) the idea that we could better understand motion in the physical world through experimentation.

In his book, *Two New Sciences,* Galileo described details of the thought experiments, simple experiments, measurements, and calculations he used as he developed concepts of motion. He began with an observation that you've almost certainly made yourself. He noticed that while a rolling ball will always come to a stop, how quickly it stops depends upon the surface underneath the ball. If given the same initial push, a ball rolling across grass will stop before a ball rolling on pavement. A ball rolling on carpet will stop before a ball rolled on a smooth, wooden floor. You can imagine that a perfectly smooth ball rolling across a perfectly smooth floor would roll for a very long time, perhaps forever. If friction is removed from the system, the ball does not need additional force to stay in motion; it will stay in motion until another force stops it.

An everyday occurrence is shown in Figure 2.9. In part A, a ball has been rolled to the left, with an initial force but no additional applied force ($F_{applied} = 0$). The resistance of the floor friction is shown by a force arrow, F_{floor}. There is also a small force of resistance applied to the ball by all of the air molecules in its way, F_{air}. The net force, F_{net}, opposes the forward movement of the ball. The rolling speed decreases until the ball finally comes to a complete stop.

To keep the ball moving, a force must be maintained on the ball that balances out the resistance applied by friction. How much force is needed? For a constant speed, the force must equal $F_{floor} + F_{air}$. If such a force is applied, whether by your hand, the wind, or another projectile, the forces will balance out and the ball will stay in motion forever.

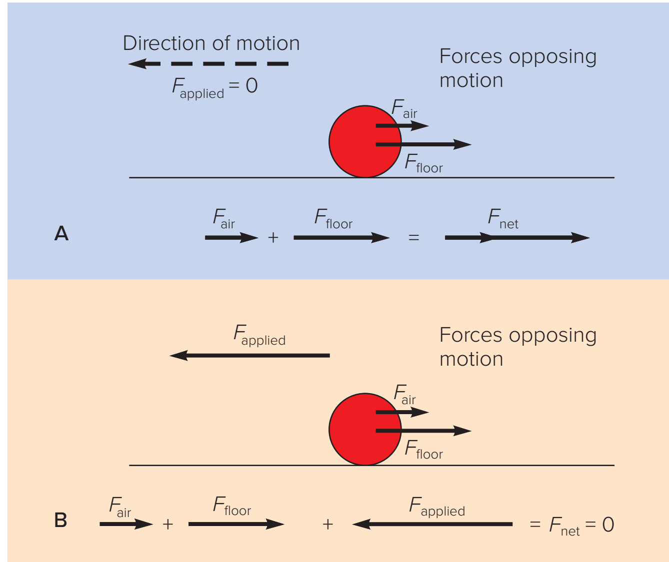
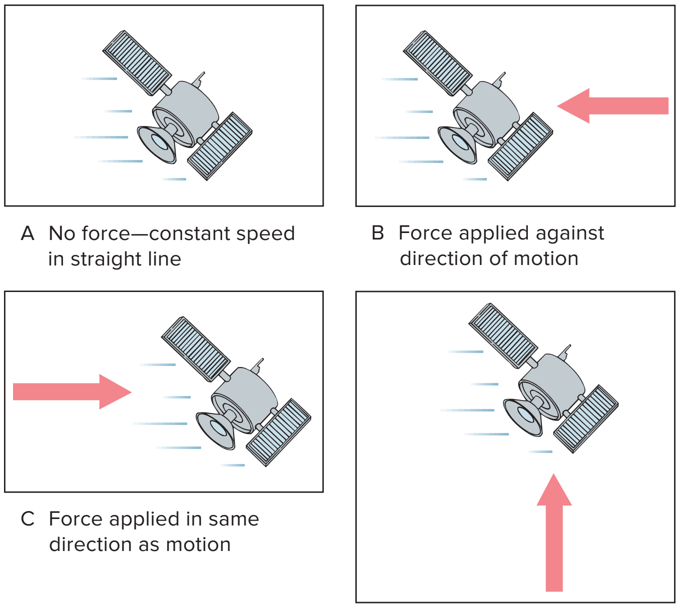


FIGURE 2.9 The following focus is on horizontal forces only: (*A*) This ball is rolling to your left with no forces in the direction of motion. The sum of the force of floor friction (F_{floor}) and the force of air friction (F_{air}) results in a net force opposing the motion, so the ball slows to a stop. (*B*) A force is applied to the moving ball, perhaps by a hand that moves along with the ball. The force applied ($F_{applied}$) equals the sum of the forces opposing the motion, so the ball continues to move with a constant velocity.

If the air is removed from the environment, there would be less resistance and less force would be needed to keep the ball in motion. If the floor could be made smoother, there would also be less resistance and less force would be needed to maintain the balls' speed. If all of the friction between the ball and floor could be removed, the ball would continue rolling until something acted to stop it. This was the kind of reasoning and testing that Galileo did when he challenged the Aristotelian view that a force was necessary to keep an object moving.

While Aristotle accurately described that rolling balls always come to rest, he was incorrect in his explanation of why that happens. He argued that it is the "natural state" of objects to be at rest. Galileo's work describes *why* they must be pushed or pulled and reveals the true nature of the motion of objects. He asserted that objects tend to continue in their state, whether that's to be in motion or to be still, until something applies a force to that object. The behavior of matter to persist in its state of motion is called **inertia.** Inertia is the *tendency of an object to remain in unchanging motion whether actually moving or at rest, when the net force is zero.* The development of this concept changed the way people viewed the natural state of an object and opened the way for further understandings about motion.

Today we have the opportunity to observe objects in friction-free settings that are not possible on Earth. A space



A No force—constant speed in straight line

B Force applied against direction of motion

C Force applied in same direction as motion

D Force applied sideways to direction of motion

FIGURE 2.10 Explain how the combination of drawings (*A–D*) illustrates inertia.

probe that is launched from Earth's surface by an initial rocket blast will move across the Solar System without any additional forces to keep it in motion. A satellite moving through free space will continue to do so with no unbalanced forces acting on it (Figure 2.10A). An unbalanced force is needed to slow the satellite (Figure 2.10B), increase its speed (Figure 2.10C), or change its direction of travel (Figure 2.10D).

2.4 FALLING OBJECTS

Did you ever wonder what happens to a falling rock during its fall? Aristotle reportedly thought that a rock falls at a uniform speed that is proportional to its weight. Thus, a heavy rock would fall at a faster uniform speed than a lighter rock. As stated in a popular story, Galileo discredited Aristotle's thinking by dropping a solid iron ball and a solid wooden ball simultaneously from the top of the Leaning Tower of Pisa (Figure 2.11). Both balls, according to the story, hit the ground nearly at the same time. To do this, they would have to fall with the same velocity. In other words, the velocity of a falling object does not depend on its weight. (Any difference in freely falling bodies is explainable by air resistance.)

Soon after the time of Galileo, the air pump was invented. The air pump could be used to remove the air from a glass tube. The effect of air resistance on falling objects could then be demonstrated by comparing how objects fall in the air with how they fall in an evacuated glass tube. You know that a coin falls faster than a feather when they are dropped together in the air. The air in the room provides a resisting frictional force—air resistance—that slows the larger feather more than the smaller coin. When objects fall toward Earth without air resistance being considered, they are said to be in **free fall.** Free fall considers only gravity and neglects air resistance.

Galileo concluded that light and heavy objects fall together in free fall, but he also wanted to know the details of what was going on while they fell. He now knew that the velocity of an object in free fall was *not* proportional to the weight of the object. He observed that the velocity of an object in free fall *increased* as the object fell and reasoned from this that the velocity of the falling object would have to

Myths, Mistakes, & Misunderstandings

Walk or Run in Rain?

Is it a mistake to run in rain if you want to stay drier? One idea is that you should run because you spend less time in the rain, so you will stay drier. On the other hand, this is true only if the rain lands on the top of your head and shoulders. If you run, you will end up running into more raindrops on the larger surface area of your face, chest, and front of your legs.

Two North Carolina researchers looked into this question with one walking and the other running over a measured distance while wearing cotton sweatsuits. They then weighed their clothing and found that the walking person's sweatsuit weighed more. This means you should run to stay drier.

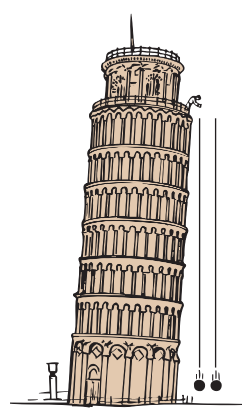


FIGURE 2.11 According to a widespread story, Galileo dropped two objects with different weights from the Leaning Tower of Pisa. They reportedly hit the ground at about the same time, discrediting Aristotle's view that the speed during the fall is proportional to weight.

CONCEPTS Applied

Falling Bodies

Galileo concluded that all objects fall together, with the same acceleration, when the upward force of air resistance is removed. It would be most difficult to remove air from the room, but it is possible to do some experiments that provide some evidence of how air influences falling objects.

1. Take a sheet of paper and your textbook and drop them side by side from the same height. Note the result.
2. Place the sheet of paper on top of the book and drop them at the same time. Do they fall together?
3. Crumple the sheet of paper into a loose ball, and drop the ball and book side by side from the same height.
4. Crumple a sheet of paper into a very tight ball, and again drop the ball and book side by side from the same height.

Explain any evidence you found concerning how objects fall.

be (1) somehow proportional to the *time* of fall and (2) somehow proportional to the *distance* the object fell. If the time and distance were both related to the velocity of a falling object at a given time and distance, how were they related to each other? To answer this question, Galileo made calculations involving distance, velocity, and time and, in fact, introduced the concept of acceleration. The relationships between these variables are found in the same three equations that you have already learned. Let's see how the equations can be rearranged to incorporate acceleration, distance, and time for an object in free fall.

Step 1: Equation 2.1 gives a relationship between average velocity ($\bar{v}$), distance (d), and time (t). Solving this equation for distance gives

$$d = \bar{v}t$$

Step 2: An object in free fall should have uniformly accelerated motion, so the average velocity could be calculated from equation 2.3,

$$\bar{v} = \frac{v_f + v_i}{2}$$

Substituting this equation in the rearranged equation 2.1, the distance relationship becomes

$$d = \left(\frac{v_f + v_i}{2}\right)(t)$$

Step 3: The initial velocity of a falling object is always zero just as it is dropped, so the v_i can be eliminated,

$$d = \left(\frac{v_f}{2}\right)(t)$$

Step 4: Now you want to get acceleration into the equation in place of velocity. This can be done by solving equation 2.2 for the final velocity (v_f), then substituting. The initial velocity (v_i) is again eliminated because it equals zero.

$$a = \frac{v_f - v_i}{t}$$

$$v_f = at$$

$$d = \left(\frac{at}{2}\right)(t)$$

Step 5: Simplifying, the equation becomes

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

equation 2.4

Thus, Galileo reasoned that a freely falling object should cover a distance *proportional to the square of the time of the fall* ($d \propto t^2$). In other words the object should fall 4 times as far in 2 s as in 1 s ($2^2 = 4$), 9 times as far in 3 s ($3^2 = 9$), and so on. Compare this prediction with Figure 2.12.

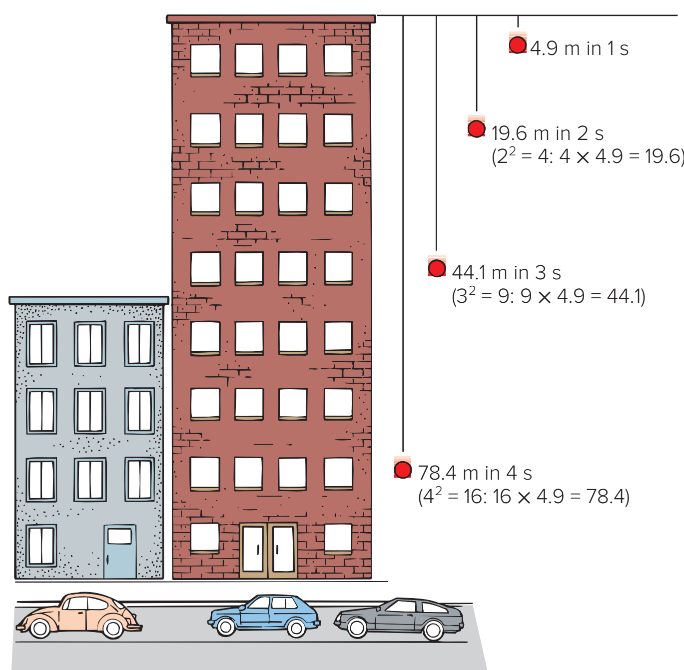


FIGURE 2.12 An object dropped from a tall building covers increasing distances with every successive second of falling. The distance covered is proportional to the square of the time of falling ($d \propto t^2$).

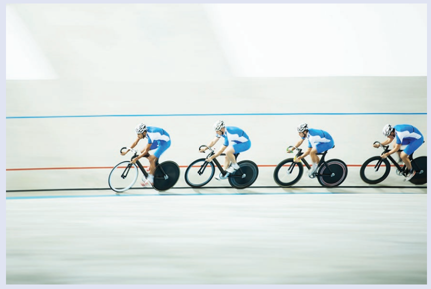
A Closer Look

A Bicycle Racer's Edge

Galileo was one of the first to recognize the role of friction in opposing motion. As shown in Figure 2.9, friction with the surface and air friction combine to produce a net force that works against anything that is moving on the surface. This article is about air friction and some techniques that bike riders use to reduce that opposing force—perhaps giving them an edge in a close race.

The bike riders in Box Figure 2.1 are forming a single-file line, called a *paceline,* because the slipstream reduces the air resistance for a closely trailing rider. Cyclists say that riding in the slipstream of another cyclist will save much of their energy. They can move 8 km/h faster than they would expending the same energy riding alone.

In a sense, riding in a slipstream means that you do not have to push as much air out of your way. It has been estimated that at 32 km/h, a cyclist must move a little less than one-half ton of air out of the way every minute. Along with the problem of moving air out of the way, there are two basic factors related to air resistance. These are (1) a turbulent versus a smooth flow of air and (2) the problem of frictional drag. A turbulent flow of air contributes to air resistance because it causes the air to separate slightly on the back side, which increases the pressure on the front of the moving object. This is why racing cars, airplanes, boats, and other racing vehicles are streamlined to a teardroplike shape. This shape is not as likely to have the lower-pressure-producing air turbulence behind (and resulting greater pressure in front) because it smooths, or streamlines, the air flow.



BOX FIGURE 2.1 The object of the race is to be in the front, to finish first. If this is true, why are racers forming single-file lines? Fredrick Kippe/Alamy Stock Photo

The frictional drag of air is similar to the frictional drag that occurs when you push a book across a rough tabletop. You know that smoothing the rough tabletop will reduce the frictional drag on the book. Likewise, the smoothing of a surface exposed to moving air will reduce air friction. Cyclists accomplish this "smoothing" by wearing smooth Lycra clothing and by shaving hair from arm and leg surfaces that are exposed to moving air. Each hair contributes to the overall frictional drag, and removal of the arm and leg hair can thus result in seconds saved. This might provide enough of an edge to win a close race. Shaving legs and arms and the wearing of Lycra or some other tight, smooth-fitting garments are just a few of the things a cyclist can do to gain an edge. Perhaps you will be able to think of more ways to reduce the forces that oppose motion.

Galileo checked this calculation by rolling balls on an inclined board with a smooth groove in it. He used the inclined board to slow the motion of descent in order to measure the distance and time relationships, a necessary requirement since he lacked the accurate timing devices that exist today. He found, as predicted, that the falling balls moved through a distance proportional to the square of the time of falling. This also means that the *velocity of the falling object increased at a constant rate*, as shown in Figure 2.13. Recall that a change of velocity during some time period is called *acceleration*. In other words, a falling object *accelerates* toward the surface of Earth.

Since the velocity of a falling object increases at a constant rate falling faster and faster and faster, this must mean that falling objects are *uniformly accelerated* by the force of gravity. *All objects in free fall experience a constant acceleration.* During each second of fall, the object falling toward Earth's surface gains 9.8 m/s (32 ft/s) in velocity. This gain is the acceleration of the falling object, 9.8 m/s^2 (32 ft/s^2).

The acceleration due to gravity is important in a number of situations, so the acceleration from this force is given a special symbol, ***g***.

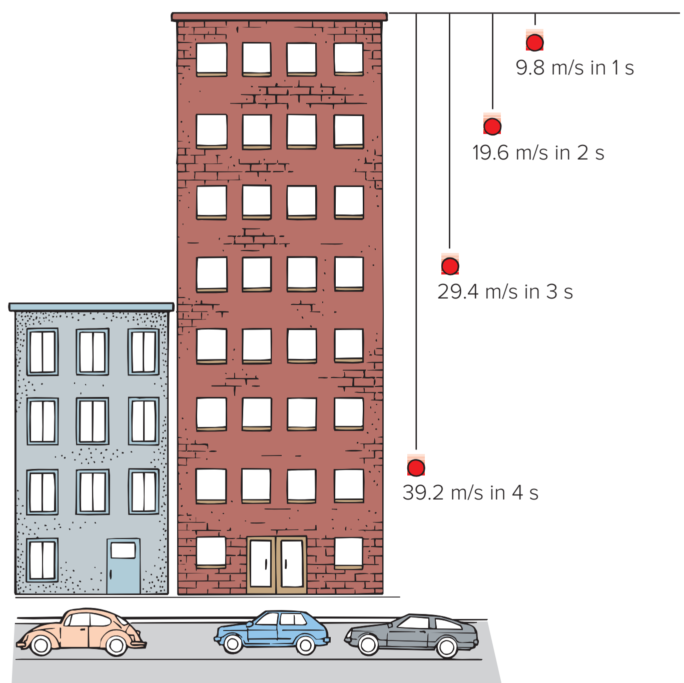


FIGURE 2.13 The velocity of a falling object increases at a constant rate, 9.8 m/s^2.