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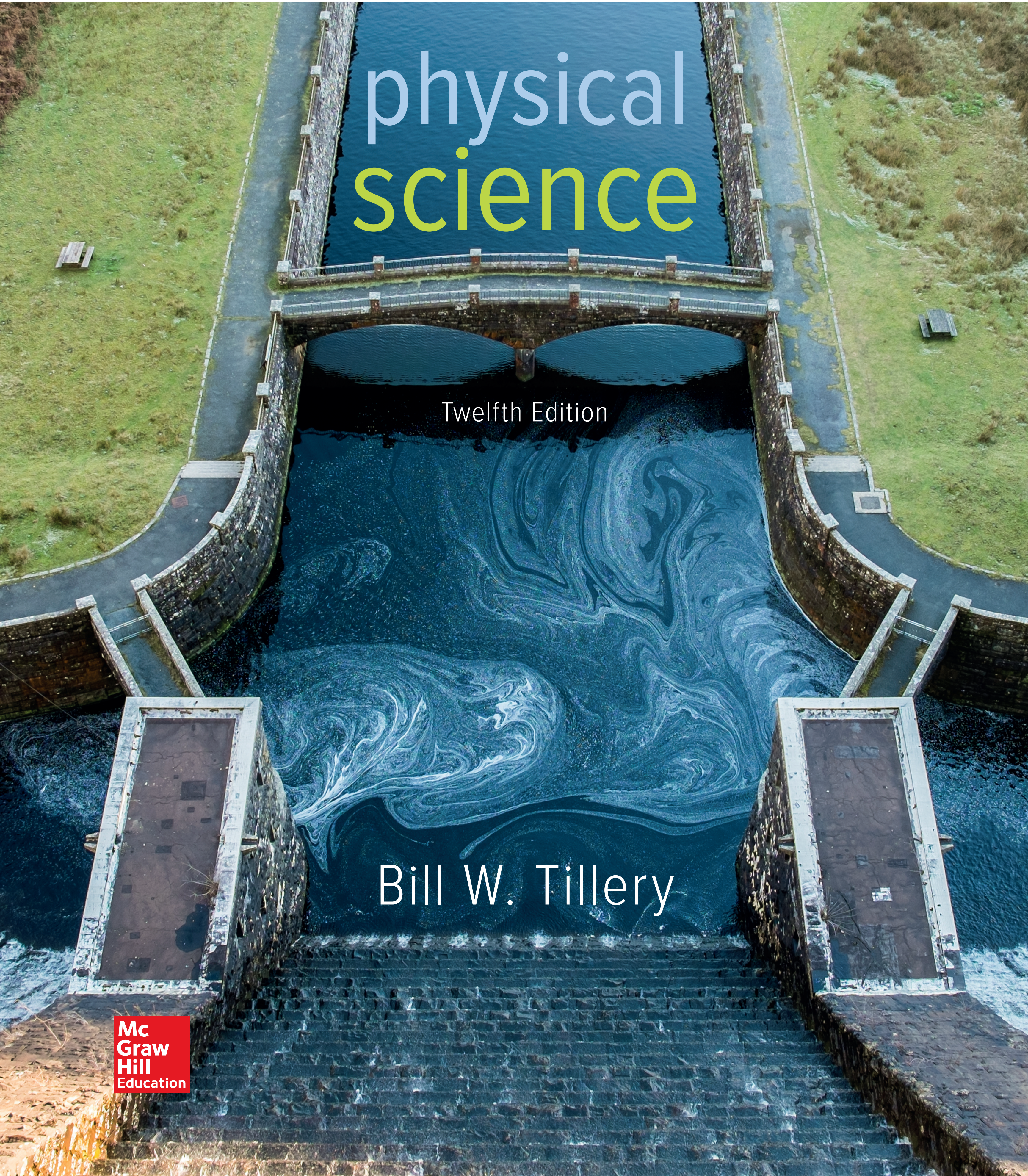
physical science

Twelfth Edition



Bill W. Tillery

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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

TWELFTH EDITION

PHYSICAL SCIENCE

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UNIVERSITY OF WYOMING

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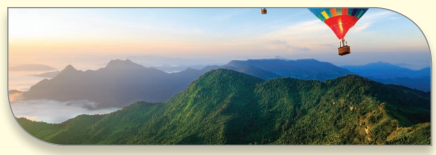

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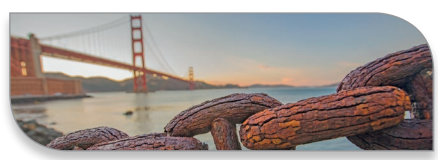

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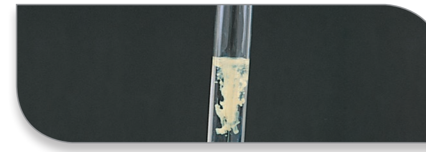

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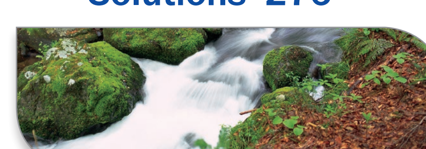

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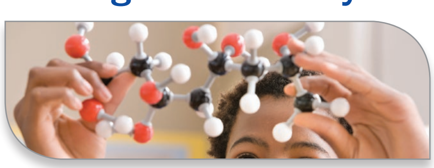

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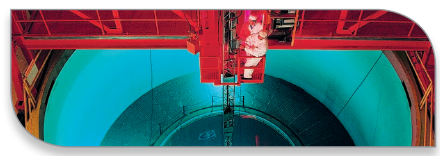

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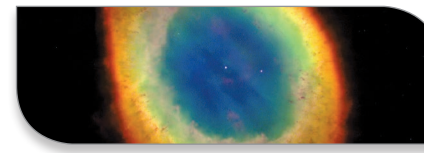

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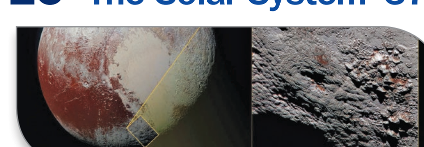

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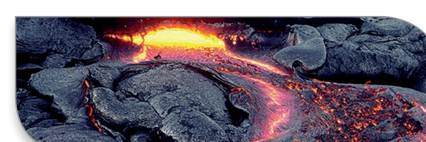

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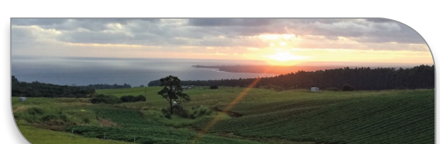

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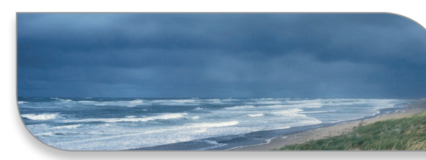

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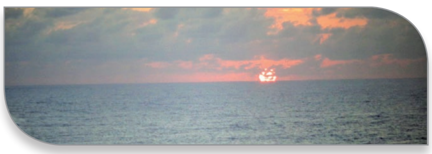

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PREFACE

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.

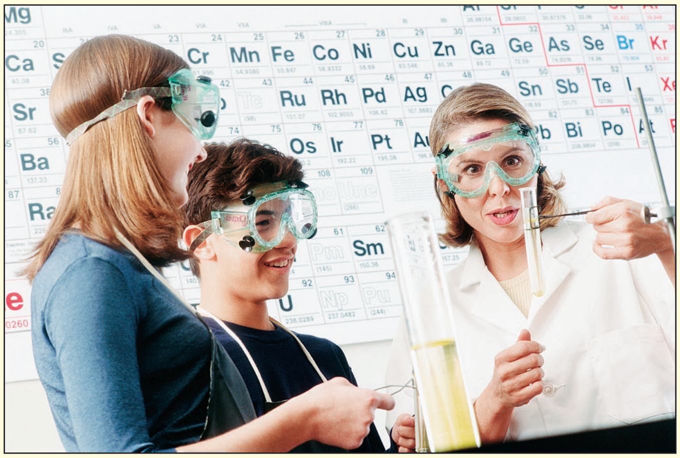
ORGANIZATION

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 twelfth 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 facelift. More than 80 new photographs and illustrations have been included.
- All chapters have been revised to increase readability of the text, figure and illustrations.
- The revised Chapter 15 includes completely revised information related to Mercury, Venus and Mars based upon information from the latest space missions.
- 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.

People Behind the Science

Many chapters also have fascinating biographies that spotlight well-known scientists, past or present. From these *People Behind the Science* biographies, students learn about the human side of the science: physical science is indeed relevant, and real people do the research and make the discoveries. These readings present physical science in real-life terms that students can identify with and understand.

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 twelfth 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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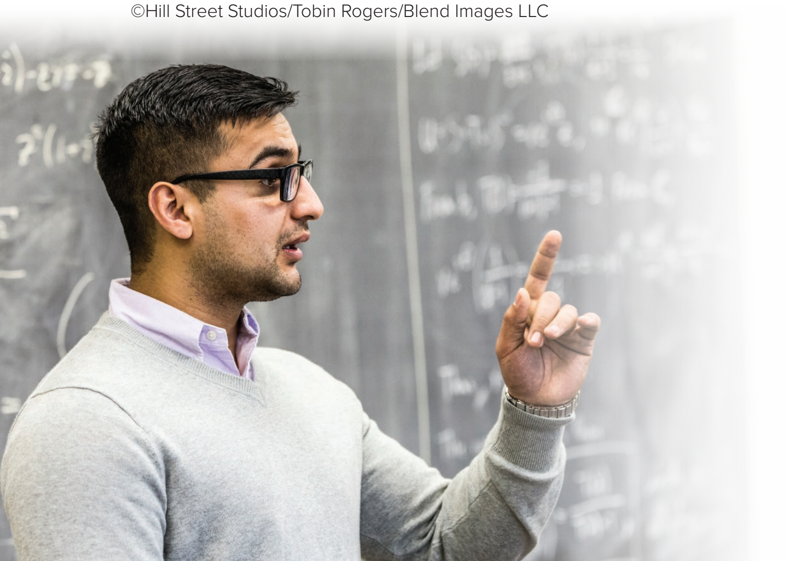

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“I really liked this app—it made it easy to study when you don't have your text-book in front of you.”

- Jordan Cunningham,
Eastern Washington University

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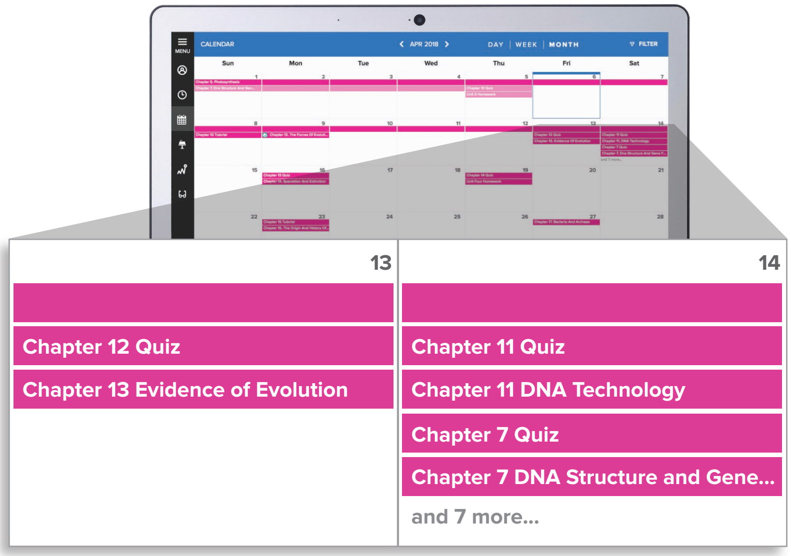

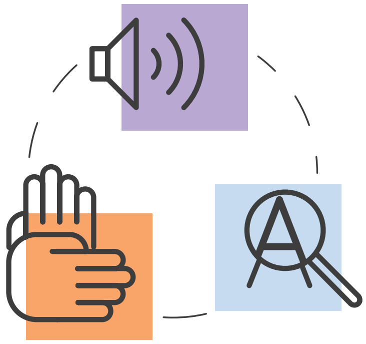

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Timothy F. Slater, *University of Wyoming*
Gina Seegers Szablewski, *University of Wisconsin - Milwaukee*

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

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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 thirteen books, has written more than one hundred peer-reviewed journal articles, and been the recipient of numerous teaching awards.

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.

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

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

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

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.

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.

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. ©McGraw-Hill Education/Bill Tillery, photographer

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,

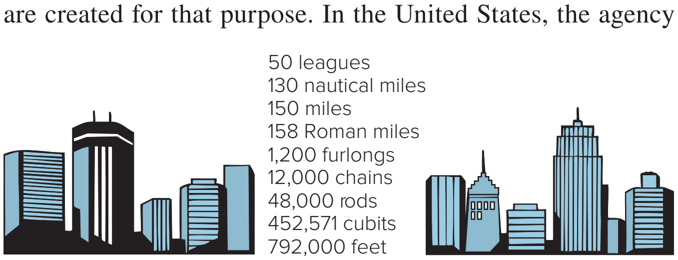

FIGURE 1.4 Which of the listed units should be used to describe the distance between these hypothetical towns? Is there an advantage to using any of the units? Any could be used, and when one particular unit is officially adopted, it becomes known as the *standard unit*.

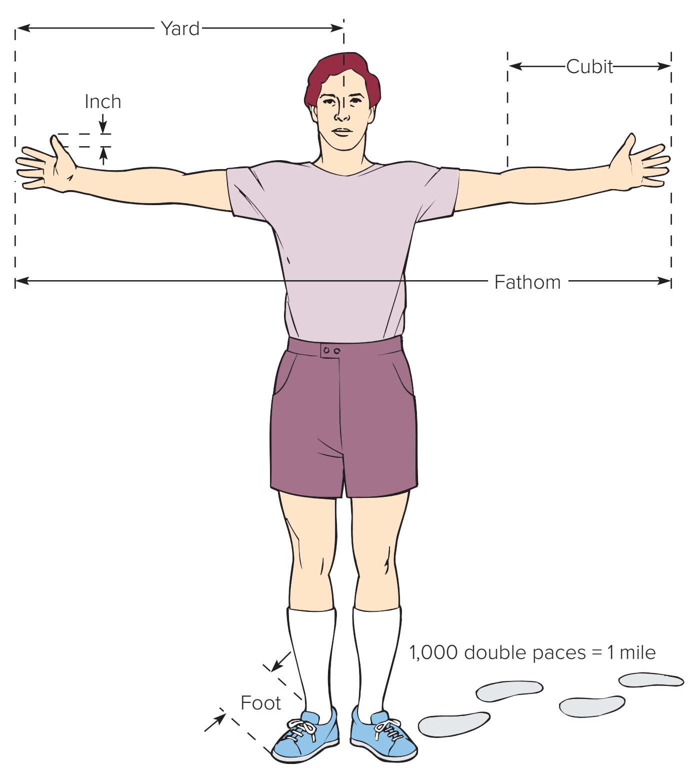

FIGURE 1.5 Many early units for measurement were originally based on the human body. Some of the units were later standardized by governments to become the basis of the English system of measurement.

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

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.

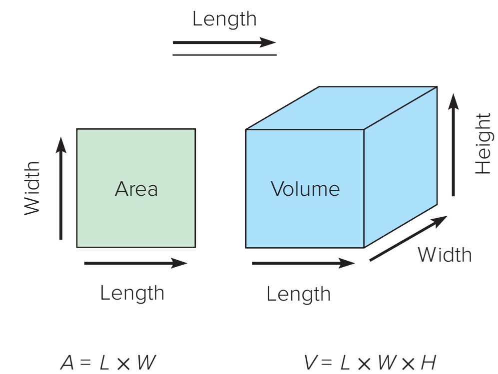

FIGURE 1.6 Area, or the extent of a surface, can be described by two length measurements. Volume, or the space that an object occupies, can be described by three length measurements. Length, however, can be described only in terms of how it is measured, so it is called a *fundamental property*.

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}

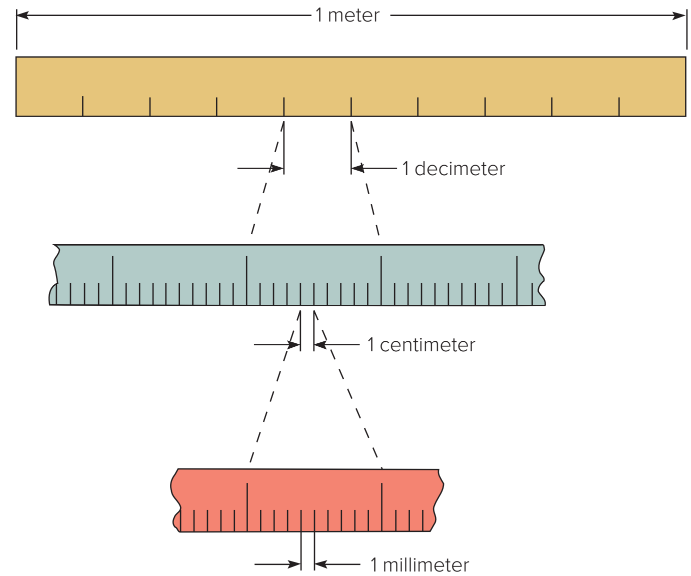

FIGURE 1.7 Compare the units shown here. How many millimeters fit into the space occupied by 1 centimeter? How many millimeters fit into the space of 1 decimeter? How many millimeters fit into the space of 1 meter? Can you express all these as multiples of 10?

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,

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

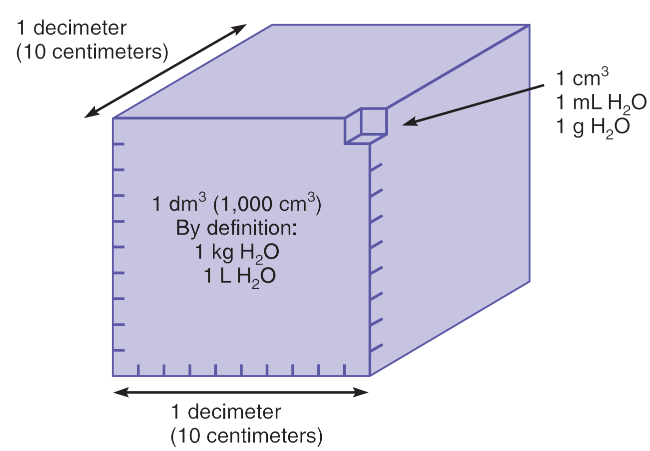

FIGURE 1.8 A cubic decimeter of water (1,000 cm^3) has a liquid volume of 1 L (1,000 mL) and a mass of 1 kg (1,000 g). Therefore, 1 cm^3 of water has a liquid volume of 1 mL and a mass of 1 g.

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

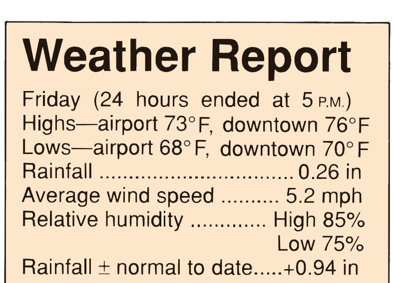

FIGURE 1.9 A weather report gives exact information, data that describe the weather by reporting numerically specified units for each condition being described.

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.

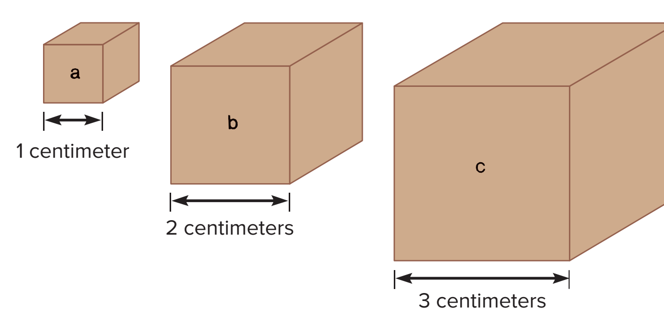

FIGURE 1.10 Cube *a* is 1 centimeter on each side, cube *b* is 2 centimeters on each side, and cube *c* is 3 centimeters on each side. These three cubes can be described and compared with data, or measurement information, but some form of analysis is needed to find patterns or meaning in the data.

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

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

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

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

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

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

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

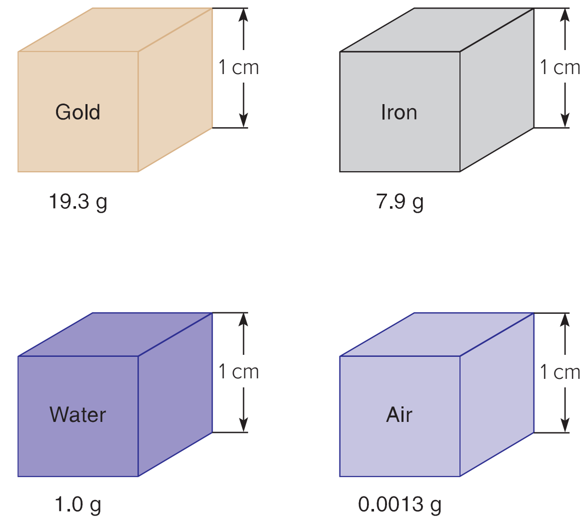

FIGURE 1.11 Equal volumes of different substances do not have the same mass, as these cube units show. Calculate the densities in g/cm^3. Do equal volumes of different substances have the same density? Explain.

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

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

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

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?