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PHYSICAL SCIENCE, 4/E

Bill W. Tillery
Arizona State University

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Physics Chapters From
Physical Science, 4/E

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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 = 5280 ft = 1.609 km
1 light-year = 9.461×10^{15} m

Mass

1 lb = 453.6 g (where g = 9.80 m/sec^2)
1 kg = 2.205 lb (where g = 9.80 m/sec^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 kWhr = 3.60×10^6 J = 860 kcal
1 hp = 550 ft·lb/sec = 746 W
1 W = 0.738 ft·lb/sec
1 Btu/hr = 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/hr = 0.2778 m/sec = 0.6214 mi/hr
1 m/sec = 3.60 km/hr = 2.237 mi/hr = 3.281 ft/sec
1 mi/hr = 1.61 km/hr = 0.447 m/sec = 1.47 ft/sec
1 ft/sec = 0.3048 m/sec = 0.6818 mi/hr

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
Giga-	G	1,000,000,000 times the unit
Mega-	M	1,000,000 times the unit
Kilo-	k	1,000 times the unit
Hecto-	h	100 times the unit
Deka-	da	10 times the unit
Base Unit		
Deci-	d	0.1 of the unit
Centi-	c	0.01 of the unit
Milli-	m	0.001 of the unit
Micro-	µ	0.000001 of the unit
Nano-	n	0.000000001 of the unit

Physical Constants

Quantity	Approximate Value
Gravity	g = 9.80 m/sec^2
Gravitational law constant	G = 6.67×10^{-11} N·m^2/kg^2
Earth radius (mean)	6.38×10^6 m
Earth mass	5.98×10^{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 = 9.00×10^9 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	6.02×10^{23}/mol
Planck's constant	6.62×10^{-34} J·sec
Speed of light (vacuum)	3.00×10^8 m/sec
Pi	π = 3.1415926536

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.

Special Treatment

Physical Science is based on two fundamental assumptions arrived at as the result of years of experience and observation from teaching the course: (a) that students taking the course often have very limited background and/or aptitude in the natural sciences; and (b) that this type of student will better grasp the ideas and principles of physical science if they 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 skill in understanding the physical sciences. Worked examples help students integrate concepts and understand the use of relationships called equations. They also serve as a problem solving model; 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 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.

Pedagogical Devices

Physical Science has an effective combination of innovative learning aids. Each chapter begins with an *introductory overview* and a brief *outline* that help students to organize their thoughts for the coming chapter materials. Each chapter ends with a brief *summary* that organizes the main concepts presented, a *summary of equations* (where appropriate) written both with words and with symbols, a list of page-referenced *key terms,* a set of *multiple-choice questions* with answers provided for immediate correction or reinforcement of major understandings, a set of *thought questions* for discussion or essay answers, and, *two sets of problem exercises* with fully worked, complete solutions for one set provided in the appendix. The set with the solutions provided is intended to be a model to help students through assigned problems in the other set. In trial classroom testing, this approach proved to be a tremendous improvement over the traditional "odd problem answers." The "odd answer only" approach provided students little help in learning problem solving skills, unless it was how to work a problem backward.

Finally, each chapter of *Physical Science* also includes a boxed *Closer Look* feature that discusses topics of special human or environmental concern (the use of seat belts, acid rain, and air pollution, for example), topics concerning interesting technological applications (passive solar homes, solar cells, and catalytic converters, for example), or topics on the cutting edge of scientific research (quarks, El Niño, and deep-ocean exploration, for example). All boxed features are informative materials that are supplementary in nature.

Supplementary Materials

Physical Science is accompanied by a variety of supplementary materials, including an instructor's manual with a Test Item File containing multiple choice test items for the text, a laboratory manual, an instructor's edition of the laboratory manual, overhead transparencies, and testing software for both the Macintosh and Windows programs. Also new to this edition is a text-specific website offering unlimited resources for both the student and instructor. The address is: **www.mhhe.com/tillery/.**

The *laboratory manual,* written and classroom tested by the author, presents a selection of laboratory exercises specifically written for the interest and abilities of nonscience majors. There are laboratory exercises that require measurement, data analysis, and thinking in a more structured learning environment. 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 manual,* also written by the text author, provides a chapter outline, an introduction/summary of each chapter, suggestions for discussion and demonstrations, multiple choice questions (with answers) that can be used as resources for cooperative teaching, and answers and solutions to all end-of-chapter questions and exercises not provided in the text.

The *text specific website* provides instructional resources for both the student and the instructor. With a home page dedicated to both students and professors, they will be able to access a Table of Contents page, which will provide links to many resources. Available to them are links to chapter resources, links to web-related resources, on-line quizzes, and links to collaborative exercises. Thought provoking questions and *Invitations to Inquiry* simulating laboratory situations are also provided as on-line teaching tools. A link to the text's bulletin board provides a medium of exchange between professors and students, and a link to a text information page describes all available resources. By way of this website, students and instructors will be better able to quickly incorporate the internet into their classroom.

The author has attempted to present an interesting, helpful program that will be useful to both students and instructors. Comments and suggestions about how to do a better job of reaching this goal are welcome. Any comments about the text or other parts of the program should be addressed to:

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Tempe, AZ 85287-1504

TO THE READER

This text includes a variety of aids to the reader that should make your study of physical science more effective and enjoyable. These aids are included to help you clearly understand the concepts and principles that serve as the foundation of the physical sciences.

Overview

Chapter One 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 you can more effectively apply what you have learned.

Chapter Outlines

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.

Introductory 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. After reading the introduction, browse through the chapter, paying particular attention to topic headings and illustrations so that you get a feel for the kinds of ideas included within the chapter.

Bold-Faced Terms/Italicized

As you read each chapter you will notice that various words appear darker than the rest of the text, and others appear in italics. The darkened words, or bold-faced terms, signify key terms that you will need to understand and remember to fully comprehend the material in which they appear. These important terms are defined in context the first time they are used. Italicized words are meant to emphasize their importance in understanding explanations of ideas and concepts discussed.

Examples

Each topic discussed in the chapter contains one or more concrete examples of problems and solutions to problems as they apply to the topic at hand. Through careful study of these examples you can better appreciate the many uses of problem solving in the physical sciences.

Activities

As you look through each chapter you will find one or more activities. These activities are simple investigative exercises that you can perform at home or in the classroom to demonstrate important concepts and reinforce your understanding of them.

Closer Look Readings

One or more boxed *Closer Look* readings are included on topics of special interest to the general population as well as the science community. The *Closer Look* features serve to underscore the relevance of physical science in confronting the many issues we face in our day-to-day lives.

End-of-Chapter Features

At the end of each chapter you will find the following materials: (a) a *Summary* that highlights the key elements of the chapter; (b) a *Summary of Equations* (Chapters 1–9, 11–13, 15) to reinforce your retention of them; (c) a listing of *Key Terms* that are page-referenced where you will find the terms defined in context; (d) a multiple choice quiz entitled *Applying the Concepts* to test your comprehension of the material covered; (e) *Questions for Thought* designed to challenge you to demonstrate your understanding of the topics; and (f) a section entitled *Parallel Exercises* (Chapters 1–15). 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 D. 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 solution in Appendix D you will gain confidence in tackling the parallel exercises in Group B, and thus, reinforce your problem solving skills.

End-of-Text Materials

At the back of the text you will find appendices that will give you additional background details, charts, and answers to chapter exercises. There is also a glossary of all key terms, an index organized alphabetically by subject matter, and special tables printed on the inside covers for reference use.

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TABLE OF CONTENTS

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

CHAPTER | One

The World Around You

OUTLINE

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 and the day-to-day weather, to the not so obvious, such as how atoms are put together. Your physical surroundings include natural things as well as things that people have made and used (Figure 1.1). 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.

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. Objects can be any size, but people are usually concerned with objects that are larger than a pinhead and smaller than a house. Outside these limits, the actual size of an object is difficult for most people to comprehend.

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 (Figure 1.2). 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? Thinking about this question is troublesome for most 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.

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." 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

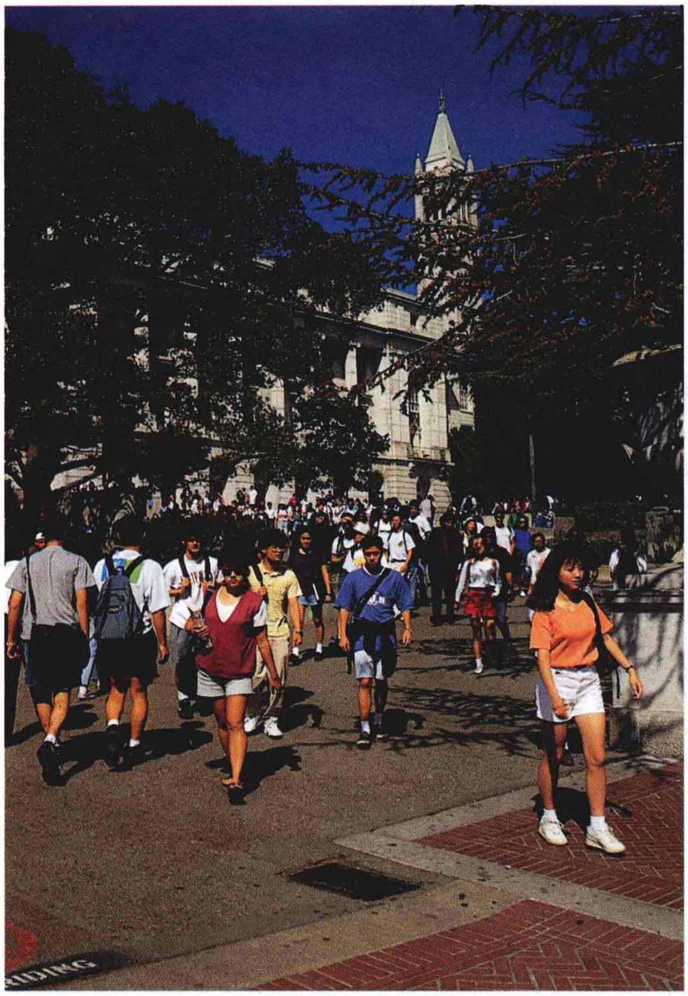


FIGURE 1.1
Your physical surroundings include naturally occurring and manufactured objects such as sidewalks and buildings.

FIGURE 1.2
What is your concept of a chair? Are all of these pieces of furniture chairs? 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 of a loosely defined concept.

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.

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 with 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.

Activities

1. Find out how people communicate about the properties of objects. Ask several friends to describe a paper clip while their hands are behind their backs. Perhaps they can do better describing a goatee? Try to make a sketch that represents each description.
2. Ask two classmates to sit back to back. Give one of them a sketch or photograph that shows an object in some detail, perhaps a guitar or airplane. This person is to describe the properties of the object *without naming it.* The other person is to make a scaled sketch from the description. Compare the sketch to the description; then see how the use of measurement would improve the communication.

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, which specifies how the comparison is made, and (3) *counting* how many standard units describe the property being considered.

As an example of how the measurement process works, consider the property of *length.* Most people are familiar with the concept of the length of something (long or short), the use of length to describe distances (close or far), and the use of length to describe heights (tall or short). The referent units used for measuring length are the familiar inch, foot, and mile from the English system and the centimeter, meter, and kilometer of the metric system. These systems and specific units will be discussed later. For now, imagine that these units do not exist but that you need to measure the length and width of this book. This imaginary exercise will illustrate how the measurement process eliminates vagueness and assumption in communication.

The first requirement in the measurement process is to choose some referent unit of length. You could arbitrarily choose something that is handy, such as the length of a standard paper clip, and you could call this length a "clip." Now you must decide on a procedure to specify how you will use the clip unit. You could define some specific procedures. For example:

1. Place a clip parallel to and on the long edge, or length, of the book so the end of the referent clip is lined up with the bottom edge of the book. Make a small pencil mark at the other end of the clip, as shown in Figure 1.4.
2. Move the outside end of the clip to the mark and make a second mark at the other end. Continue doing this until you reach the top edge of the book.
3. Compare how many clip replications are in the book length by counting.
4. Record the length measurements by writing (a) how many clip replications were made and (b) the name of the clip length.

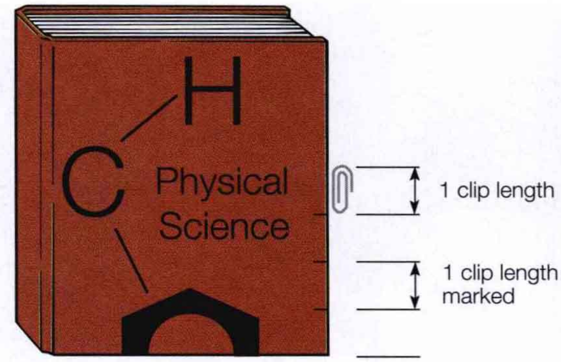


FIGURE 1.4
As an example of the measurement process, a standard paper-clip length is selected as a referent unit. The unit is compared to the property that is being described. In this example, the property of the book length is measured by counting how many clip lengths describe the length.

If the book length did not measure to a whole number of clips, you might need to divide the clip length into smaller subunits to be more precise. You could develop a *scale* of the basic clip unit and subunits. In fact, you could use multiples of the basic clip unit for an extended scale, using the scale for measurement rather than moving an individual clip unit. You could call the scale a "clipstick" (as in yardstick or meterstick).

The measurement process thus 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.

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 implying the procedure for obtaining the number. Referent units must be defined and established, however, if others are to

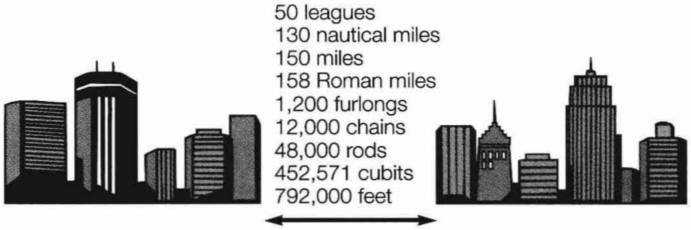


FIGURE 1.5

Any of these units and values could have been used at some time or another to describe the same distance between these hypothetical towns. Any unit could be used for this purpose, but when one particular unit is officially adopted, it becomes known as the *standard unit*.

understand and reproduce a measurement. It would be meaningless, for example, for you to talk about a length in "clips" if other people did not know what you meant by a "clip" unit. When standards are established the referent unit is called a **standard unit** (Figure 1.5). 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 appropriately named the National Institute of Standards and Technology.

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 referent unit based on the length of the racetrack at the local stadium ("stadia" is the plural of stadium). 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 1.6). The inch, for example, 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 was not the same size. Beginning in the 1300s, the sizes of the units were gradually standardized by various English kings (Table 1.1). In 1879, the United States, along with sixteen other countries, signed the *Treaty of the Meter*, defining the English units in terms of the metric system. The

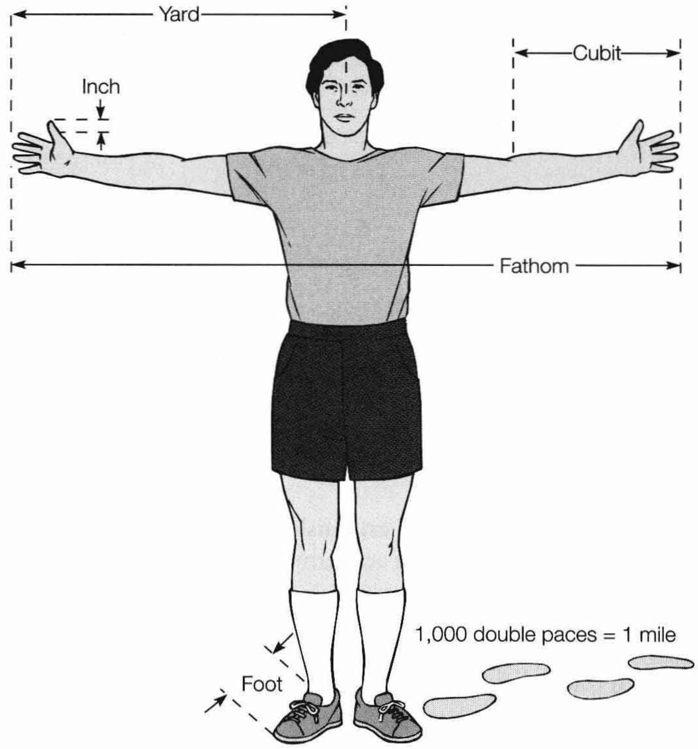


FIGURE 1.6

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 Early conversion table for English units of volume

Two Quantities	Equivalent Quantity
2 mouthfuls	= 1 jigger
2 jiggers	= 1 jack
2 jacks	= 1 jill
2 jills	= 1 cup
2 cups	= 1 pint
2 pints	= 1 quart
2 quarts	= 1 pottle
2 pottles	= 1 gallon
2 gallons	= 1 pail
2 pails	= 1 peck
2 pecks	= 1 bushel

TABLE 1.2 The SI standard units

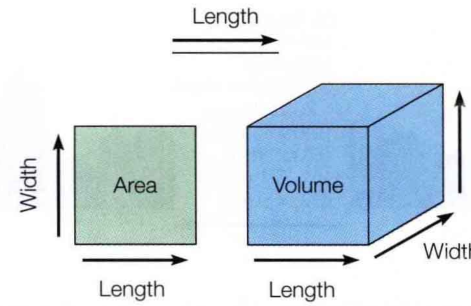
Property	Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

United States thus became officially metric, but not entirely metric in everyday practice.

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. In 1960, six standard metric units were established by international agreement. The *International System of Units,* abbreviated *SI,* is a modernized version of the metric system. Today, the SI system has seven units that define standards for the properties of length, mass, time, electric current, temperature, amount of substance, and light intensity (Table 1.2). The standard 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.

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 1.7). 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 a future chapter.



$A = L \times W$ $V = L \times W \times H$

FIGURE 1.7

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 was originally defined in 1793 as one ten-millionth of the distance between the geographic North Pole and the equator of the earth. In order to make this standard accessible, the length of a meter was determined and a one-meter metal bar was made as a prototype. This prototype was used to make copies for the countries of the world. The United States received its prototype meter in 1890. Beginning in 1893, the yard was legally defined in terms of the meter. Metal bars, however, tend to expand and contract with changes in temperature, so every precise measurement with the bar required a correction for the temperature. In 1960 the definition of a meter was changed to one that used the wavelength of a certain color of light given off from a particular element. In 1983 the definition was again changed, this time in terms of 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 one 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 certain metal cylinder 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 the earth. They are, however, two completely different properties

A CLOSER LOOK | The Leap Second

Most people have heard of a leap year, but not a leap second. A *leap year* is needed because the Earth does not complete an exact number of turns on its axis while completing one trip around the Sun. Our calendar system was designed to stay in step with the seasons with 365 day years and a 366 day year (leap year) every fourth year.

Likewise, our clocks are occasionally adjusted by a one second increment known as a *leap second.* The leap second is needed because the Earth does not have a constant spin. Coordinated Universal Time is the worldwide scientific standard of time keeping. It is based upon Earth's rotation and is kept accurate to within microseconds with carefully maintained atomic clocks. A leap second is a second added to Coordinated Universal Time to make it agree with astronomical time to within 0.9 second.

In 1955 astronomers at the U.S. Naval Observatory and the National Physical Laboratory in England measured the relationship between the frequency of the cesium atom (the standard of time) and the rotation of the Earth at a particular period of time. The standard atomic clock second was defined to be equivalent to the fraction 1/31,556,925.9747 of the year 1900—or, an average second for that year. This turned out to be the time required for 9,192,631,770 vibrations of the cesium 133 atom. The second was defined in 1967 in terms of the length of time required for 9,192,631,770 vibrations of the cesium 133 atom. So, the atomic second was set equal to an average second of Earth rotation time near the turn of the twentieth century, but defined in terms of the frequency of a cesium atom.

The Earth is constantly slowing from the frictional effects of the tides. Evidence of this slowing can be found in records of ancient observations of eclipses. From these records it is possible to determine the slowing of the Earth to be roughly 1–3 milliseconds per day per century. This causes the Earth's rotational time to slow with respect to the atomic clock time. It has been nearly a century since the referent year used for the definition of a second and the difference is now roughly 2 milliseconds per day. Other factors also affect the Earth's spin, such as the wind from hurricanes, so that it is necessary to monitor the Earth's rotation continuously and add or subtract leap seconds when needed.

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 3. 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). The earth's spin was found not to be as constant as thought, so the second was redefined in 1967 to be the duration required for a certain number of vibrations of a certain cesium atom. A special spectrometer called an "atomic clock" measures these vibrations and keeps time with an accuracy of several millionths of a second per year.

TABLE 1.3 Some metric prefixes

Prefix	Symbol	Meaning
Giga-	G	1,000,000,000 times the unit
Mega-	M	1,000,000 times the unit
Kilo-	k	1,000 times the unit
Hecto-	h	100 times the unit
Deka-	da	10 times the unit
Unit		
Deci-	d	0.1 of the unit
Centi-	c	0.01 of the unit
Milli-	m	0.001 of the unit
Micro-	μ	0.000001 of the unit
Nano-	n	0.000000001 of the unit

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 1.3. Figure 1.8 illustrates how these prefixes are used. Suppose you wish to measure something smaller than the standard unit of length, the meter. The meter is subdivided into ten equal-sized subunits called *decimeters.* The prefix *deci-* has a meaning of "one-tenth of," and it takes 10 decimeters to equal the length of 1 meter. For even smaller measurements, each decimeter is divided into ten equal-sized subunits called *centimeters.* It takes 10 centimeters to equal 1 decimeter and 100 to equal 1 meter. In a similar fashion, each prefix up or down the metric ladder represents a simple increase or decrease by a factor of 10.

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. A cubic decimeter (dm^3) of pure water at 4°C was *defined* to have a mass of 1 kilogram (kg). This definition

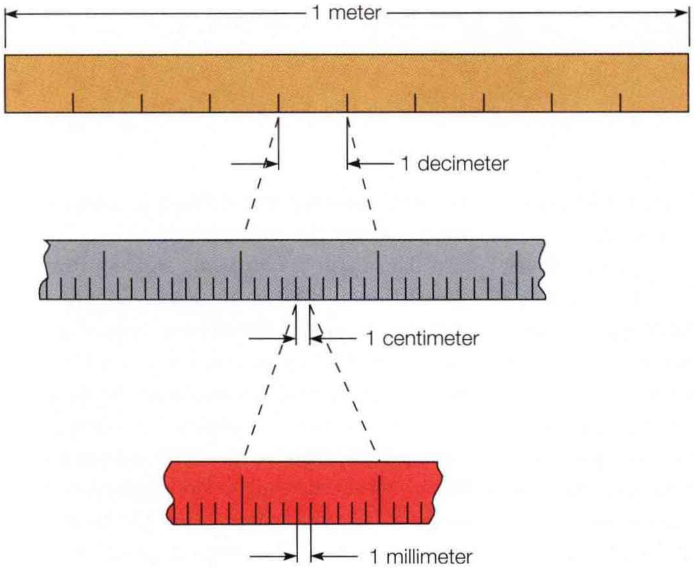


FIGURE 1.8

Prefixes are used with the standard units of the metric system to represent larger or smaller amounts by factors of 10. Measurements somewhat smaller than the standard unit of the meter, for example, are measured in decimeters. The prefix "deci-" means "one-tenth of," and it takes 10 decimeters to equal the length of 1 meter. For even smaller measurements, the decimeter is divided into 10 centimeters. Continuing to even smaller measurements, the centimeter is divided into 10 millimeters. There are many prefixes that can be used (Table 1.3), but all are related by multiples of 10.

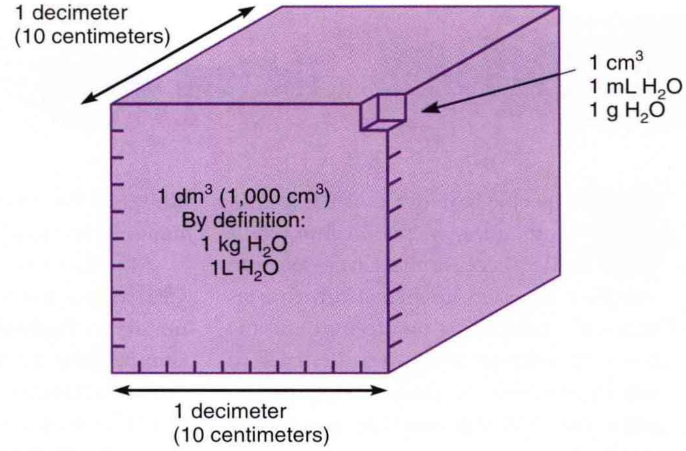
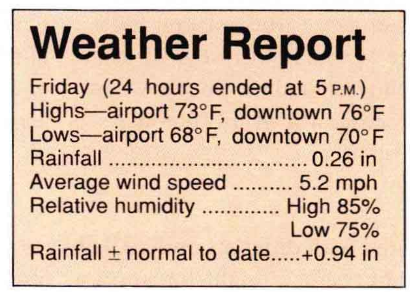


FIGURE 1.9

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.


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 1.10

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

was convenient because it created a relationship between length, mass, and volume. As illustrated in Figure 1.9, 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

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

or, for smaller amounts,

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

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 inches for rainfall (Figure 1.10). 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.