Chapter 1
An Introduction to Chemistry

I would watch the buds swell in spring, the mica glint in the granite, my own hands, and I would say to myself: "I will understand this, too. I will understand everything.

Primo Levi (1919–87)
Italian chemist and author, *The Periodic Table*

It is human nature to wonder—about the origins of the universe and of life, about their workings, and even about their meanings. We look for answers in physics, biology, and the other sciences, as well as in philosophy, poetry, and religion. Primo Levi could have searched for understanding in many ways, but his wondering led him to study chemistry…and so has yours, though you may not yet know why.

1.1 What is Chemistry, and What Can Chemistry Do for You?

One thing is certain: Once you start studying chemistry, all kinds of new questions will begin to occur to you. Let's consider a typical day.

Your alarm rings early, and you are groggy from sleep but eager to begin working on a chemistry assignment that's coming due. Chemistry has taught you that there are interesting answers to questions you might once have considered silly and childish. Preparing tea, for example, now makes you wonder why the boiling water bubbles and produces steam while the teakettle retains its original shape. How do the tea leaves change the color of the water while the teabag remains as full and plump as ever? Why does sugar make your tea sweet, and why is the tea itself bitter?

You settle down with tea and newspaper, and the wondering continues. An article about methyl bromide, a widely used pesticide, says some scientists think it damages the ozone layer. What *are* methyl bromide and ozone? How does one destroy the other, and why should we care? How can we know if the ozone really is being depleted?

Later, as you drive to the library to get some books you need to complete that chemistry assignment, you wonder why gasoline burns and propels your

An understanding of chemistry opens up a window to the world around you.

car down the road. How does it pollute the air we breathe and what does the catalytic converter do to minimize the pollution? At the library, you wonder why some books that are hundreds of years old are still in good shape while other books that are only 50 years old have pages that are brown, brittle, and crumbling. Can the books with damaged pages be saved?

Chemists can answer all these questions and others like them. They are scientists who study the structure of material substances—collectively called matter—and the changes that they undergo. Matter can be solid like sugar, liquid like water, or gaseous like the exhaust from your car's tailpipe. **Chemistry** is often defined as the study of the structure and behavior of matter.

Chemists do a lot more than just answer questions. Industrial chemists are producing new materials to be used to build lighter and stronger airplanes, more environmentally friendly disposable cups, and more efficient anti-pollution devices for your car. Pharmaceutical chemists are developing new drugs to fight cancer, control allergies, and even grow hair on bald heads.

In the past, the chemists' creations have received mixed reviews. The chlorofluorocarbons (CFCs) used as propellants in aerosol cans are now known to threaten the Earth's protective ozone layer. The durable plastics that chemists created have proved *too* durable, so when they are discarded, they remain in the environment for a long, long time. One of the messages you will find in this book is that despite the occasional mistakes and failures, most chemists have a strong social conscience. Not only are they actively developing new chemicals to make our lives easier, safer, and more productive, but they are also working to clean up our environment and minimize the release of chemicals that might be harmful to our surroundings (see Special Topic 1.1: *Green Chemistry*).

As you read on in this book, you will find, perhaps to your disappointment, that only limited portions of each chapter provide direct answers to real-life questions. An introductory chemistry text, such as this one, must focus instead on teaching basic principles and skills. Some of the things you need to learn in order to understand chemistry may seem less than fascinating, and it will not always be easy to see why they are useful. Try to remember that the fundamental concepts and skills will soon lead you to a deeper understanding of the physical world.

Before you could run, you needed to learn how to walk. Before you could read a book or write a paper, you needed to learn the alphabet, build your vocabulary, and understand the basic rules of grammar. Chemistry has its own "alphabet" and vocabulary, as well as many standards and conventions, that allow chemists to communicate and to do efficient, safe, and meaningful work. Learning the symbols for the common chemical elements, the rules for describing measurements, or the conventions for describing chemical changes might not be as interesting as finding out how certain chemicals in our brains affect our moods, but they are necessary steps in learning chemistry.

This chapter presents some suggestions for making your learning process easier and introduces you to some of the methods of scientific measurement and reporting. You will then be ready for Chapter 2, which introduces chemical calculations, and Chapter 3, which gives you a first look at some of chemistry's underlying concepts.

Special Topic 1.1 Green Chemistry

With knowledge comes the burden of responsibility.

Paul T Anastas and Tracy C. Williamson,
Green Chemistry

The chemical industry has made many positive contributions to modern life, but these improvements have come at a price. The chemical products themselves, the chemicals used to produce them, and the byproducts of their production have sometimes been harmful to our health or the environment. Concern about these dangers has lead to a movement in the chemical industry that is sometimes called Green Chemistry or Environmentally Benign Chemistry. Its goal is to produce, process, and use chemicals in new ways that pose fewer risks to humans and their environment.

In support of this goal, President Clinton inaugurated the Green Chemistry Program in March 1995, to be coordinated by the Environmental Protection Agency. As part of this program, the Green Chemistry Challenge Awards were set up, as part of the Green Chemistry Program, to "recognize and promote fundamental and innovative chemical methodologies that accomplish pollution prevention and that have broad application in industry."

Among the first award recipients was the Rohm and Haas Company, which received the Green Chemistry Challenge's 1996 Designing Safer Chemicals Award for the development of 4,5-dichloro-2-n-octyl-4-isothiazolin-3-one, otherwise known as Sea-Nine® antifoulant. As soon as a new ship goes into the water, various plants and animals begin to grow on its bottom. This growth slows the ship's progress and causes other problems as well, ultimately costing the shipping industry an estimated $3 billion per year. Substances called antifoulants are painted on the bottom of ships to prevent the unwanted growth, but most of them can be harmful to the marine environment. Sea-Nine® is a more environmentally friendly chemical than the alternatives because it breaks down in the ocean more quickly and does not accumulate in marine organisms.

This is only one example of the progress that Green Chemistry is making. Others will be presented in later chapters.

Source: P. T. Anastas and T. C. Williams, Eds. *Green Chemistry*; (Washington DC: American Chemical Society,1996).

New, environmentally friendly marine antifoulants protect ships without polluting the water.

1.2 Suggestions for Studying Chemistry

The will to succeed is important, but what's more important is the will to prepare.

Basketball Coach, Bobby Knight

Let's face it. Chemistry has a reputation for being a difficult subject. One reason is that it includes so many different topics. Individually, they are not too difficult to understand, but collectively, they are a lot to master. Another reason is that these topics must be learned in a cumulative fashion. Topic A leads to topic B, which is important for understanding topic C, and so on. If you have a bad week and do not study topic B very carefully, topic C will not make much sense to you. Because chemistry is time-consuming and cumulative, you need to be very organized and diligent in studying it.

There is no *correct* way to study chemistry. Your study technique will be decided by your current level of chemical knowledge, the time you have available, your strengths as a student, and your attitude toward the subject. The following is a list of suggestions to help you take chemistry's special challenges in stride.

Use the Review Skills sections in this textbook. Starting with Chapter 2, each chapter begins with a section called **Review Skills**, complemented at the end of the chapter by a set of review questions that test those skills. The Review Skills section and the review questions identify the specific skills from earlier chapters that are necessary for success in the new chapter. If you have trouble with the tasks on the Review Skills list, you will have trouble with the chapter, so promise yourself that you will always review the topics listed in the Review Skills section before beginning a new chapter.

Read each chapter in the textbook before it is covered in lecture. There are several good reasons why a relaxed pre-lecture reading of each chapter is important. It provides you with a skeleton of knowledge that you can flesh out mentally during the lecture, at the same time guaranteeing that there will be fewer new ideas to absorb as you listen to your teacher talk. If you already know a few things, you will be better prepared to participate in class.

Attend class meetings, take notes, and participate in class discussions. You will get much more out of a lecture, discussion section, or laboratory—and will enjoy it more—if you are actively involved. Don't hesitate to ask questions or make comments when the lecture confuses you. If you have read the chapter before coming to class and paid attention to the lecture and you still have a question, you can be fairly certain that other students have that question too and will appreciate your asking for clarification.

Reread the chapter, marking important sections and working the practice exercises. In the second reading, mark key segments of the chapter that you think you should reread before the exam. Do not try to do this in the first reading, because you will not know what parts are most important until you have an overview of the material the chapter contains. It is a good idea to stop after reading each section of text and ask yourself, "What have I just read?" This will keep you focused and help you to remember longer.

You will find **Examples** in each chapter that show how to do many of the tasks that you will be asked to do on exams. The examples are followed by **Exercises** that you should work to test yourself on these tasks. The answers to these exercises are found at the end of the book. If you have trouble with a practice exercise, look more closely at the example that precedes it, but don't get bogged down on any one topic. When a new concept or an exercise gives you trouble, apply the *15-minute rule*: If you have spent more than 15 minutes on an idea or problem and you still do not understand it, write down what you do not understand and ask your instructor or another student to explain it.

Use the chapter objectives as a focus of study. At the end of each chapter is a list of **Chapter Objectives** that provides a specific description of what you should be able to do after studying the chapter. Notations in the text margins show you where to find the information needed to meet each objective. Your instructor may wish to add to the list or remove objectives from it.

Many of the objectives begin with, "Explain…" or "Describe…". You might be tested on these objectives in short essay form, so it is a good idea to actually write your responses down. This will force you to organize your thoughts and develop a concise explanation that will not take too much time to write on the exam. If you do it conscientiously, perhaps using color to highlight key phrases, you will be able to visualize your study sheet while taking the exam.

Many of the objectives refer to stepwise procedures. This book will suggest one procedure, and sometimes your instructor will suggest another. Write out the steps that you think will work best for you. The act of writing will help you remember longer, and you will find it much easier to picture a study sheet written out in your own handwriting than one printed in this book.

Use the computer-based tools that accompany the course. This textbook is accompanied by an Internet site that supplements the text. If you have access to it, you will find it useful at this stage in your studying.

Work some of the problems at the end of the chapter. Do not try the end-of-chapter problems too soon. They are best used as a test of what you have and have not mastered in the chapter after all the previous steps have been completed. Note that many of the problems are accompanied by the number of the learning objective to which they correspond. (In fact, the problems serve as examples of ways in which you might be tested on various chapter objectives.) Use the same *15-minute rule* for the problems as for the chapter concepts and exercises: If you have spent more than 15 minutes on any one problem, it is time to seek help.

I hear and I forget.
I see and I remember.
I do and I understand.
Chinese proverb

Ask for help when you need it. Don't be shy. Sometimes five minutes in the instructor's office can save you an hour or more of searching for answers by other means. You might also consider starting a study group with fellow students. It can benefit those of you who are able to give help as well as those who need it. There is no better way to organize one's thoughts than to try to communicate them to someone else. There may be other ways to get help. Ask your instructor what is available.

He who neglects to drink of the spring of experience is likely to die of thirst in the desert of ignorance.
Ling Po

Review for the exam. Read the list of objectives, asking yourself whether you can meet each one. Every time the answer is "No," spend some time making it "Yes." This might mean meeting with your instructor or study group, rereading this text, or reviewing your notes. Ask your instructor which objectives are being emphasized on the exam and how you are going to be tested on them. Your lecture notes can also provide clues to this. Lastly, work some more of the end-of-chapter problems. This will sharpen your skills and improve your speed on the exam.

1.3 The Scientific Method

It's as simple as seeing a bug that intrigues you. You want to know where it goes at night; what it eats.

David Cronenberg, Canadian filmmaker

Before beginning our quest for an understanding of chemistry, let's look at how science in general is done. There is no one correct way to do science. Different scientific disciplines have developed different procedures, and different scientists approach their pursuit of knowledge in different ways. Nevertheless, most scientific work has certain characteristics in common. We can see them in the story of how scientists discovered the first treatment for Parkinson's disease, a neurological condition that progressively affects muscle control. The principal steps in the process are summarized in Figure 1.1.

Objective 2

Like most scientific work, the development of a treatment for Parkinson's disease began with *observation and the collection of data.* In the 1960's, scientists observed that South American manganese miners were developing symptoms similar to the muscle tremors and rigidity seen in Parkinson's disease. Next, the scientists made *an initial hypothesis on the basis of their observations*. Perhaps the symptoms of the manganese miners and of Parkinson's sufferers had a common cause. The initial hypothesis led to a more purposeful collection of information in the form of *systematic research or experimentation.* Systematic study of the manganese miners' brain chemistry showed that manganese interferes with the work of a brain chemical called dopamine. Because dopamine is important in the brain's control of muscle function, anyone absorbing abnormally high levels of manganese would be expected to have troubles with movement.

Objective 2

The hypothesis was refined based on the new information, and *research was designed to test the hypothesis*. Specifically, the researchers hypothesized that the brains of Parkinson's sufferers had low levels of dopamine. Brain studies showed this to be the case. *The results were published so that other scientists might repeat the research and confirm or refute the conclusions*. Because other scientists confirmed the results of the dopamine research, the *hypothesis became accepted in the scientific community.*

Objective 2

The discovery of the dopamine connection started a search for a drug that would elevate the levels of dopamine in the brain. This provides an example of what is very often the next step of the scientific method, *a search for useful applications of the new ideas*. Dopamine itself could not be used as a drug because it is unable to pass from the blood stream into the brain tissue. Instead, the researchers looked for a compound that could penetrate into the brain and then be converted into dopamine. Levodopa, or L-dopa, met these requirements. (It should be noted that significant scientific research does not always lead directly to applications, or even to a published paper. One of the main driving forces of science is just the desire to understand more about ourselves and the world around us. Any research that increases this understanding is important.)

Objective 2

The development of applications often leads to another round of hypothesizing and testing in order to refine the applications. There was some initial success with L-dopa. It caused remission of Parkinson's disease in about one-third of the patients treated and improvements in one-third of the others, but there were also problematic side effects, including nausea, gastrointestinal distress, reduced blood pressure, delusions, and mental disturbance. The drug's effects on blood pressure seem to be caused by the conversion of L-dopa to dopamine outside the brain. For this reason, L-dopa is now given with levocarbidopa, which inhibits that process.

And the cycle of hypothesis, experimentation, and finding new applications, which leads to further refinement of the hypotheses continues…

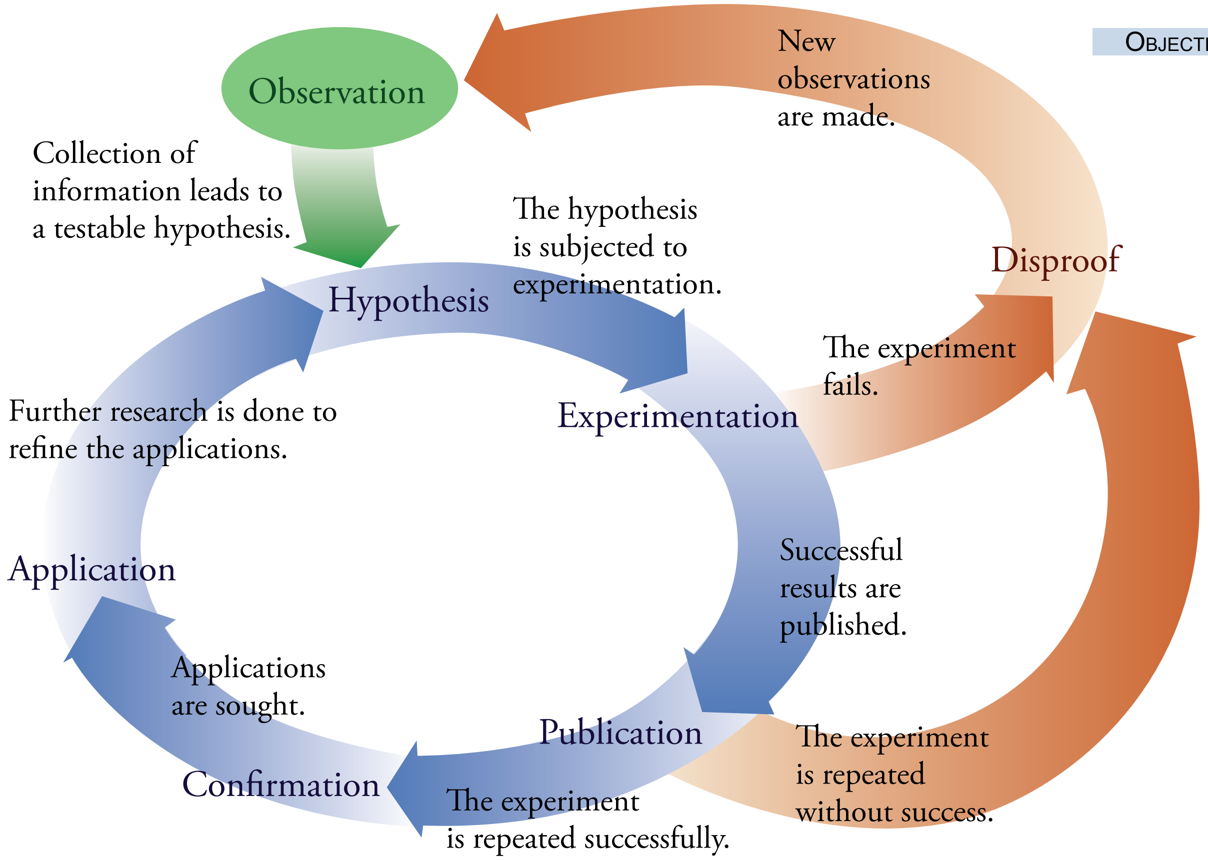


Figure 1.1
The Scientific Method

OBJECTIVE 2

1.4 Measurement and Units

Measure what is measurable and make measurable what is not so.

Galileo Galilei

The practice of chemistry demands both accuracy and clarity. The properties of matter must be measured correctly and reported without ambiguity. For example, a chemist has a lot of measuring to do while testing to see whether the pesticide methyl bromide might be destroying the protective layer of ozone gas in the earth's upper atmosphere. (The ozone in the upper atmosphere filters out harmful radiation from the sun.) She or he might add a carefully *measured* amount of methyl bromide to a reaction vessel that already contains ozone and perhaps other chemicals found in our atmosphere. In such an experiment, the temperature, too, would be carefully *measured* and adjusted to duplicate the average temperature in the ozone layer, and then the substances in the vessel might be subjected to the same *measured* amounts and kinds of radiation to which ozone is exposed in the atmosphere. Chemical changes would take place, after which the amounts of various substances found in the resultant mixture would be *measured* and reported at various times. All of these measurements of amounts, temperatures, and times must be carefully reported in a way that enables other scientists to judge the

A long-jump can be won by a centimeter.

This is US Paralympian Marlon Shirley competing in the men's F44 long jump final at the IPC 2002 Athletics World Championships.

Photo Courtesy of International Paralympic Committee (IPC)

value of the experiment.

A measurement is always reported as a **value**, a quantitative description that includes both a number and a unit. For example, before a 100-meter race is run, the distance must be measured as precisely as possible. Its value is *100 meters.* In this value, the unit is *meters* (defined below), and the number of units is *100.*

Units are quantities defined by standards that people have agreed to use to compare one event or object to another. For example, at one time the units for length were based on parts of the body. An inch (the unit) was the width of the thumb (the standard), and a foot was the length of a typical adult foot. Centuries ago you might have described the length of a cart you wanted made as eight feet, meaning eight times the length of your foot. Although the length of a foot varies for different people, this description would be accurate enough to allow the carpenter to make a cart that would fit your purpose.

As measuring techniques became more precise and the demand for accuracy increased, the standards on which people based their units were improved. In the 18^{th} century, the French invented the metric system, based on a more consistent, systematic, and carefully defined set of standards than had ever been used before. For example, the meter (or metre, from the Greek *metron*, "a measure") became the standard for length. The first definition for the standard meter was one ten-millionth of the distance from the North Pole to the Equator. This became outdated as the precision of scientist's measuring instruments improved. Today, a meter is defined as the distance light travels in a vacuum in 1/299,792,458 second. Technical instruments for measuring length are calibrated in accordance with this very accurate definition.

The International System of Measurement

The International System of Measurement (SI for *Système International d'Unitès*), a modern elaboration of the original metric system, was set up in 1960. It was developed to provide a very organized, precise, and practical system of measurement that everyone in the world could use. The SI system is constructed using seven **base units**, from which all other units are derived (Table 1.1). The chemist is not usually interested in electric currents or luminous intensity, so only the first five of the base units on Table 1.1 will appear in this text. The meaning of *mole*, the base unit for amount of substance, is explained in Chapter 3. Until then, we will use the first four base units: meter (m), kilogram (kg), second (s), and kelvin (K).

Table 1.1
Base Units for the International System of Measurement

OBJECTIVE 3

Type of Measurement	Base Unit	Abbreviation
length	meter	m
mass	kilogram	kg
time	second	s
temperature	kelvin	K
amount of substance	mole	mol
electric current	ampere	A
luminous intensity	candela	cd

SPECIAL TOPIC 1.2 Wanted: A New Kilogram

One by one, all of the SI base units except the kilogram have been defined in terms of constants of nature. For example, the speed of light in a vacuum is used to define the meter. The kilogram is the last of the standards to be based on a manufactured object. A kilogram is defined as the mass of a cylinder, made of platinum-iridium alloy, 39 mm (1.5 in.) tall and 39 mm in diameter. This cylinder has been kept in an airtight vault in Sèvres, France, since 1883. In order to avoid using (and possibly damaging) the standard itself, forty replicas were made in 1884 and distributed around the world to serve as a basis of comparison for mass. (The United States has kilogram number 20.) The scientists at the Bureau International des Poids et Mesures (BIPM) are so careful with the standard kilogram that it was only used three times in the 20th century.

There are problems associated with defining a standard in terms of an object, such as the standard kilogram. If the object loses or gains mass as a result of contact or contamination, measurements that relate to the object change. For years, the standard kilogram was maintained by a French technician named Georges Girard, who kept the cylinder clean using a chamois cloth and a mixture of ethanol and ether. Girard seemed to have just the right touch for removing contaminants without removing any metal. Now that he has retired, no one seems to be able to duplicate his procedure with the correct amount of pressure.

As the ability to measure mass becomes more exact, the need for an accurate and easily reproduced standard becomes more urgent. Already, modern instruments have shown that the copies of the standard kilogram vary slightly in mass from the original cylinder in France. Many scientists feel that the time has come to find a natural replacement for the kilogram. The International Bureau of Weights and Measures may be choosing one soon.

The copy of the standard kilogram in the United States is kilogram 20, produced in 1884.

SI Units Derived from Base Units

Many properties cannot be described directly with one of the seven SI base units. For example, chemists often need to measure volume (the amount of space that something occupies), and volume is not on the list of SI base units (Table 1.1). Rather than create a new definition for volume, we derive its units from the base unit for length, the meter. Volume can be defined as length cubed, so cubic meters, m^3, can be used as a volume unit. Various other units are derived in similar ways.

OBJECTIVE 3

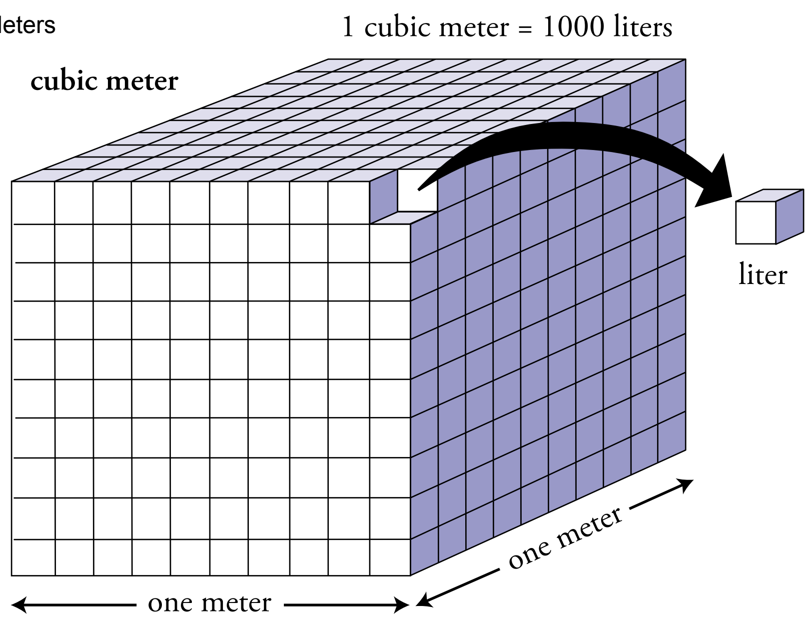
How many liters?

If you have long arms, a meter is approximately the distance from the tip of your nose to the end of your fingers when you are looking forward and extending your arm fully. A cubic meter is therefore a fairly large volume. In fact, it's inconveniently large for many uses. You'd find it awkward to buy your milk by a small fraction of a cubic meter, such as 1/1000 m^3. Scientists, too, need smaller volume units. Chemists prefer to use the liter as the base unit for volume. A liter (L) is 1/1000 (or 10^{-3}) of a cubic meter, so there are 1000 (or 10^3) liters per cubic meter[1]. See Figure 1.2.

OBJECTIVE 4

$$1\ \text{L} = 10^{-3}\ \text{m}^3 \quad \text{or} \quad 10^3\ \text{L} = 1\ \text{m}^3$$

Figure 1.2
Liters and Cubic Meters



SI Units Derived from Metric Prefixes

Because the SI base units and derived units such as the liter are not always a convenient size for making measurements of interest to scientists, a way of deriving new units that are larger and smaller has been developed. For example, the meter is too small to be convenient for describing the distance to the moon, and even the liter is too large for measuring the volume of a teardrop. Scientists therefore attach prefixes to the base units, which have the effect of multiplying or dividing the base unit by a power of 10. Table 1.2 lists some of the most common metric prefixes and their abbreviations.

[1] If you are unfamiliar with numbers such as 10^{-3} and 10^3 that are expressed using exponents and scientific notation, you should read Appendix B at the end of this text.

The unit *kilometer*, for example, is composed of the prefix *kilo-* and *meter*, the base unit for length. *Kilo-* means 10^3 (or 1000), so a kilometer is 10^3 (or 1000) meters. A kilometer is therefore more appropriate for describing the average distance to the moon: 384,403 kilometers rather than 384,403,000 meters. Units derived from metric prefixes are abbreviated by combining the abbreviation for the prefix (Table 1.2) with the abbreviation for the unit to which the prefix is attached. The abbreviation for *kilo-* is k and for *meter* is m, so the abbreviation for *kilometer* is km:

Objective 6

Objective 7

$$1 \text{ kilometer} = 10^3 \text{ meter} \quad \text{or} \quad 1 \text{ km} = 10^3 \text{ m}$$

Likewise, *micro-* means 10^{-6} (or 0.000001 or 1/1,000,000), so a micrometer is 10^{-6} meters. The abbreviation for micrometer is μm. (The symbol μ is the Greek letter mu.) The micrometer can be used to describe the size of very small objects, such as the diameter of a typical human hair, which is 3 μm. This value is easier to report than 0.000003 m.

$$1 \text{ micrometer} = 10^{-6} \text{ meter} \quad \text{or} \quad 1\ \mu\text{m} = 10^{-6} \text{ m}$$

Objective 6

Objective 7

Objective 5

Table 1.2
Some Common Metric Prefixes

Prefixes for units larger than the base unit			Prefixes for units smaller than the base unit		
Prefix	Abbreviation	Definition	Prefix	Abbreviation	Definition
giga	G	1,000,000,000 or 10^9	centi	c	0.01 or 10^{-2}
mega	M	1,000,000 or 10^6	milli	m	0.001 or 10^{-3}
kilo	k	1000 or 10^3	micro	μ	0.000001 or 10^{-6}
			nano	n	0.000000001 or 10^{-9}
			pico	p	0.000000000001 or 10^{-12}

Example 1.1 - Units Derived from Metric Prefixes

Objective 6

Objective 7

Complete the following relationships. Rewrite the relationships using abbreviations for the units.

a. 1 gigagram = ? gram
b. 1 centimeter = ? meter
c. 1 nanometer = ? meter

Solution

Refer to Table 1.2 until you have the prefixes memorized.

a. The prefix giga (G) means 10^9, so

$$1 \text{ gigagram} = \mathbf{10^9} \text{ gram} \quad \text{or} \quad 1 \text{ Gg} = \mathbf{10^9} \text{ g}$$

b. The prefix centi (c) means 10^{-2}, so

$$1 \text{ centimeter} = \mathbf{10^{-2}} \text{ meter} \quad \text{or} \quad 1 \text{ cm} = \mathbf{10^{-2}} \text{ m}$$

c. The prefix nano (n) means 10^{-9}, so

$$1 \text{ nanometer} = \mathbf{10^{-9}} \text{ meter} \quad \text{or} \quad 1 \text{ nm} = \mathbf{10^{-9}} \text{ m}$$

Exercise 1.1 - Units Derived from Metric Prefixes

Objective 5
Objective 6
Objective 7

Complete the following relationships. Rewrite the relationships using abbreviations for the units.

a. 1 megagram = ? gram
b. 1 milliliter = ? liter

More about Length Units

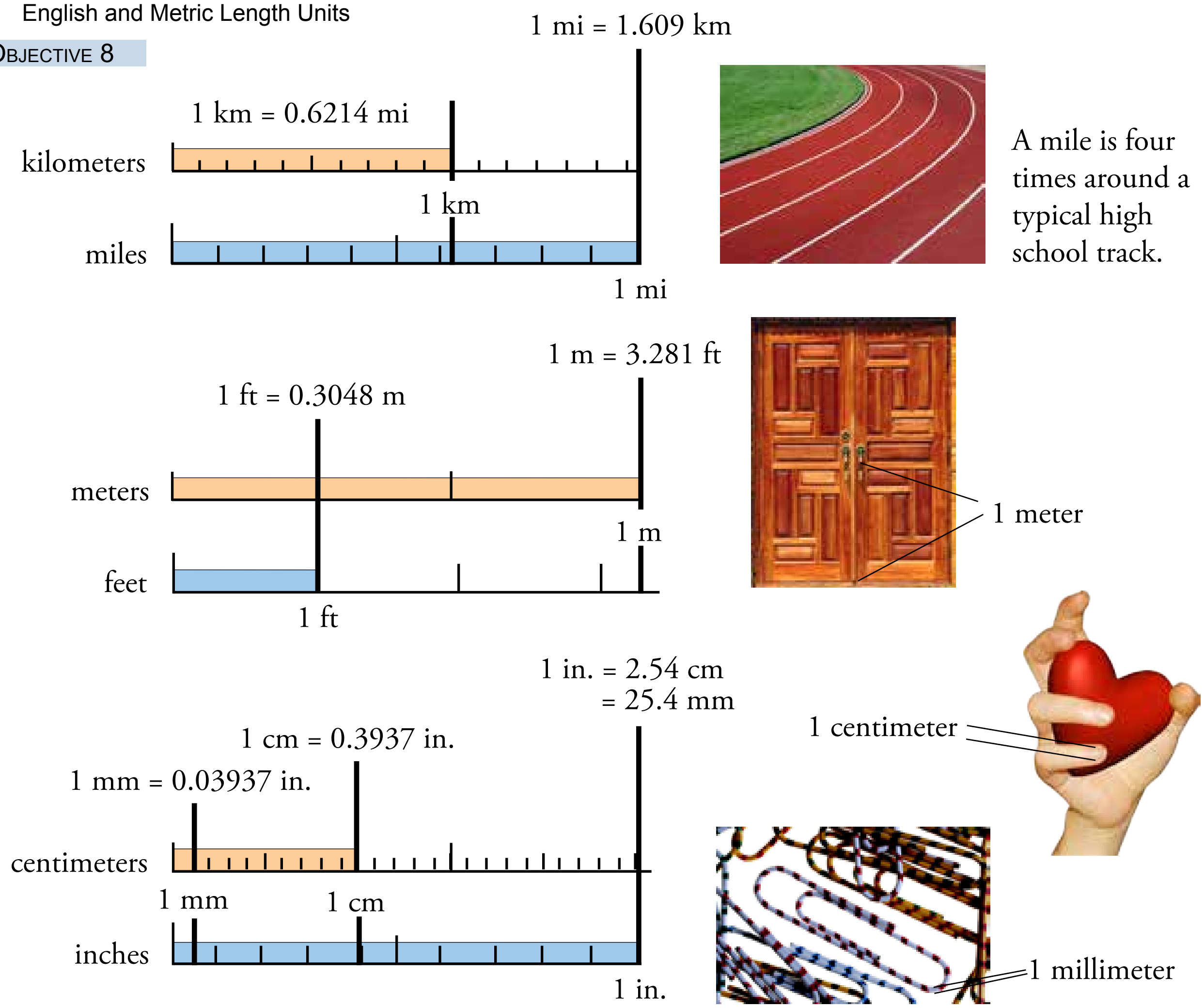
Although scientists rarely use the centuries old English system of measurement, it is still commonly used in the United States to describe quantities in everyday life. Figure 1.3 might help you to learn the relationships between metric and English length units[2].

Objective 8

A kilometer is a little more than ½ mile. The distance between the floor and a typical doorknob is about 1 meter; the width of the fingernail on your little finger is probably about 1 centimeter; and the diameter of the wire used to make a typical paper clip is about 1 millimeter. Figure 1.4 shows the range of lengths.

Figure 1.3
English and Metric Length Units

Objective 8



[2] These relationships between these units and many others are found in Appendix A.

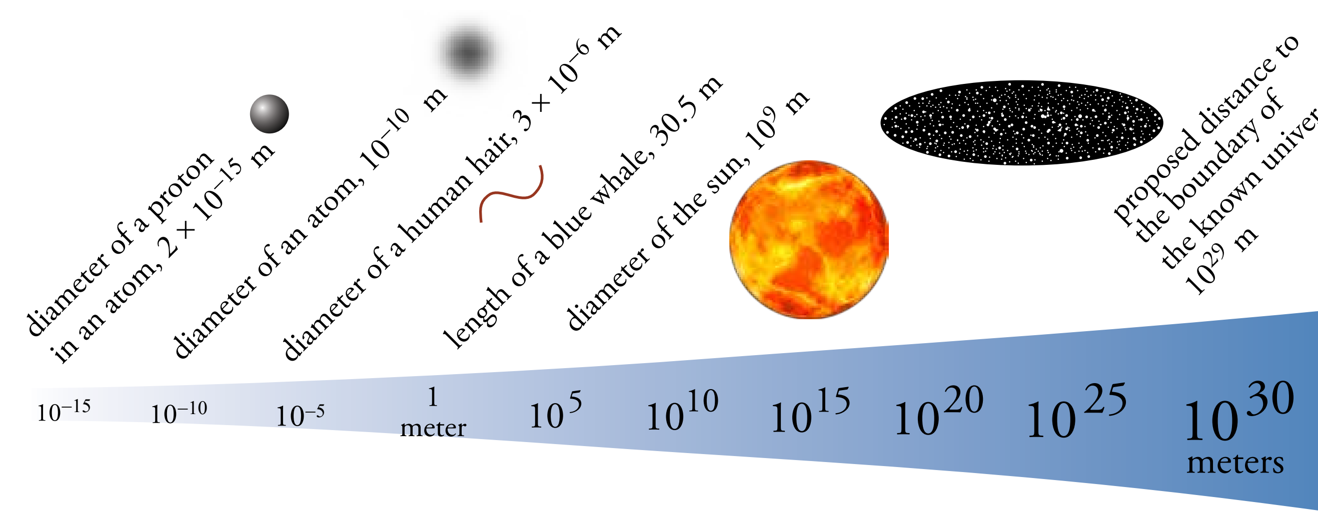


Figure 1.4
The Range of Lengths (The relative sizes of these measurements cannot be shown on such a small page. The wedge and the numbers of increasing size are to remind you that each numbered measurement on the scale represents 100,000 times the magnitude of the preceding numbered measurement.)

More About Volume Units

The relationships in Figure 1.5 might help you to develop a sense of the sizes of typical metric volume units. A liter is slightly larger than a quart. There are 4.93 milliliters in a teaspoon, so when the label on the bottle of a typical liquid children's pain reliever suggests a dosage of one teaspoon, the volume given will be about 5 milliliters. There are 29.57 milliliters per fluid ounce (fl oz). A typical bottle of nail polish contains 0.5 fl oz. Figure 1.6 on the next page shows the range of volumes.

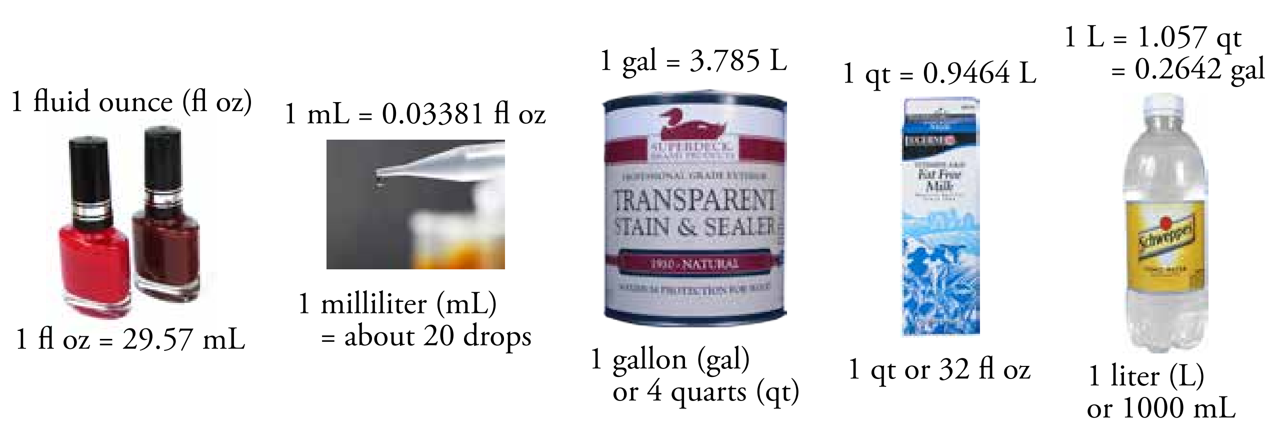
Another common volume unit is the cubic centimeter, cm^3, which is equivalent to a milliliter.

$$1\ cm^3 = 1\ mL$$

OBJECTIVE 10

OBJECTIVE 9

Figure 1.5
English and Metric Volume Units



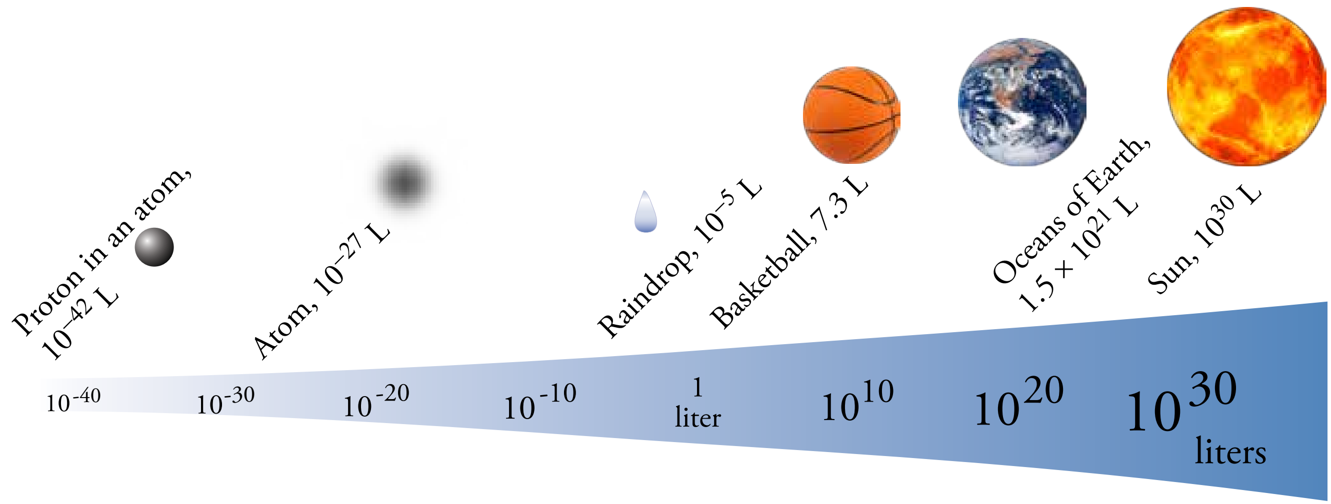


Figure 1.6 The Range of Volumes (The relative sizes of these measurements cannot be shown on such a small page. The wedge and the numbers of increasing size are to remind you that each numbered measurement on the scale represents 10,000,000,000 times the magnitude of the preceding numbered measurement.)

Mass and Weight

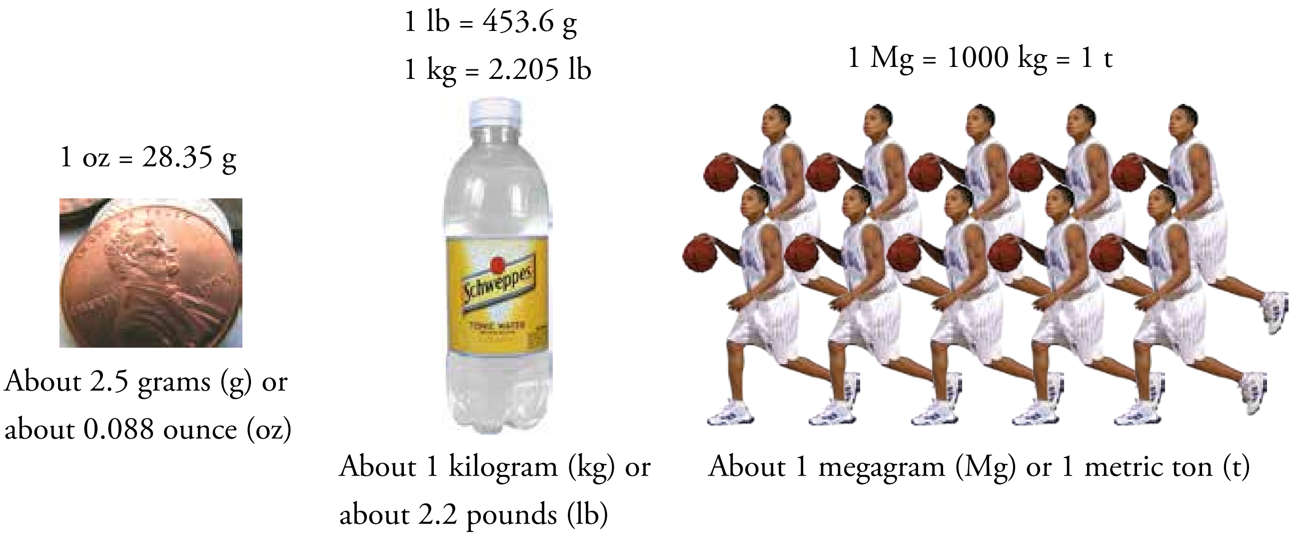
The terms mass and weight are often used as if they meant the same thing. The two properties are indeed related, but they are not identical. **Mass** is usually defined as a measure of the amount of matter in an object (**matter** is defined as anything that has mass and takes up space). In contrast, the **weight** of an object is a measure of the force of gravitational attraction between it and a significantly large body, such as the earth or the moon. An object's weight on the surface of the earth depends on its mass and on the distance between it and the center of the earth. In fact, **mass** can be defined as the property of matter that leads to gravitational attractions between objects and therefore gives rise to weight. As an object's mass increases, its weight increases correspondingly. However, as the distance between an object and the earth increases, the object's weight decreases while the amount of matter it contains, and therefore its mass, stays the same.

Objective 11

Objective 12

In the SI system, units such as gram, kilogram, and milligram are used to describe mass. People tend to use the terms *mass* and *weight* interchangeably and to describe weight with mass units too. However, because weight is actually a measure of the *force* of gravitational attraction for a body, it can be described with force units. The accepted SI force unit is the newton, N. If your mass is 65 kg, your weight on the surface of the earth—the force with which you and the earth attract each other—is 637 N. The chemist is not generally concerned with the weight of objects, so neither weight nor its unit will be mentioned in the remaining chapters of this book.

Figure 1.7 might help you to develop a sense of the sizes of typical metric mass units, and Figure 1.8 shows the range of masses.



Objective 13 Objective 14 **Figure 1.7** English and Metric Mass Units

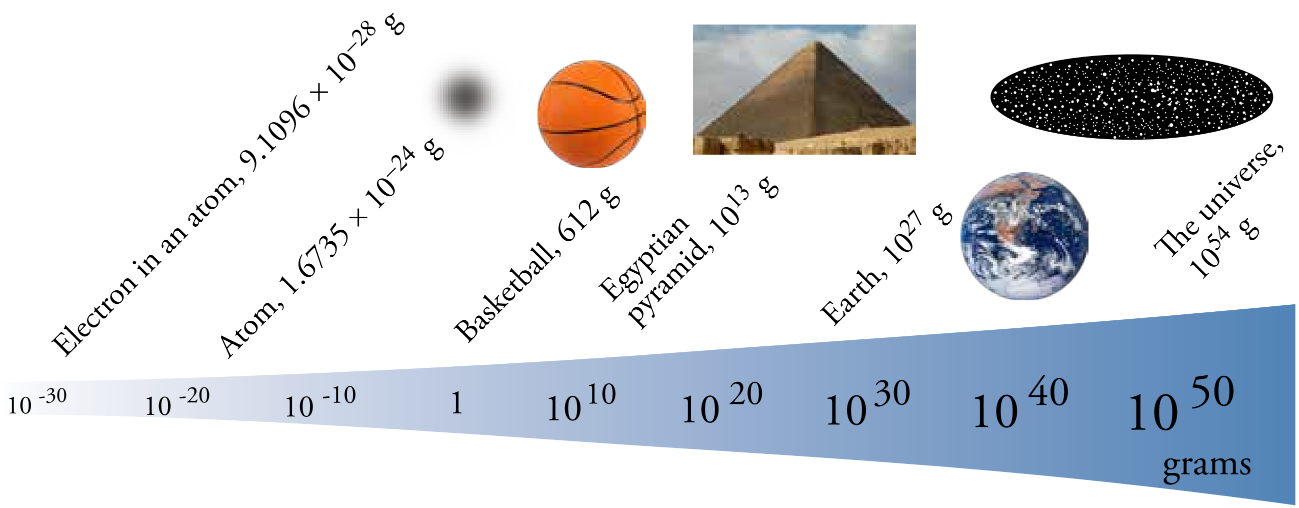


Figure 1.8 The Range of Masses (The relative sizes of these measurements cannot be shown on such a small page. The wedge and the numbers of increasing size are to remind you that each numbered measurement on the scale represents 10,000,000,000 times the magnitude of the preceding numbered measurement.)

Temperature

It may surprise you to learn that temperature is actually a measure of the average motion of the particles in a system. Instead of saying that the temperature is "higher" today than yesterday, you could say that the particles in the air are moving faster. By the time we return to a description of temperature measurements and temperature calculations, in Chapters 2 and 3, you will be much better prepared to understand the physical changes that take place when the temperature of an object changes, as well as how we measure these changes. For now, it is enough to have some understanding of the relationships between the three common temperature scales: Celsius, Fahrenheit, and Kelvin.

Objective 15

For the Celsius scale, the temperature at which water freezes is defined as 0 °C, and the temperature at which water boils is defined as 100 °C. Thus a degree Celsius, °C, is 1/100 of the temperature difference between freezing and boiling water (Figure 1.9). For the Fahrenheit scale, which is still commonly used in the US, the temperature at which water freezes is defined as 32 °F, and the temperature at which water boils is defined as 212 °F. There are 180 °F between freezing and boiling water (212 − 32 = 180), so a degree Fahrenheit, °F, is 1/180 of the temperature difference between freezing and boiling water (Figure 1.9). Note that there are 100 °C between freezing and boiling water, but there are 180 °F for the same temperature difference.

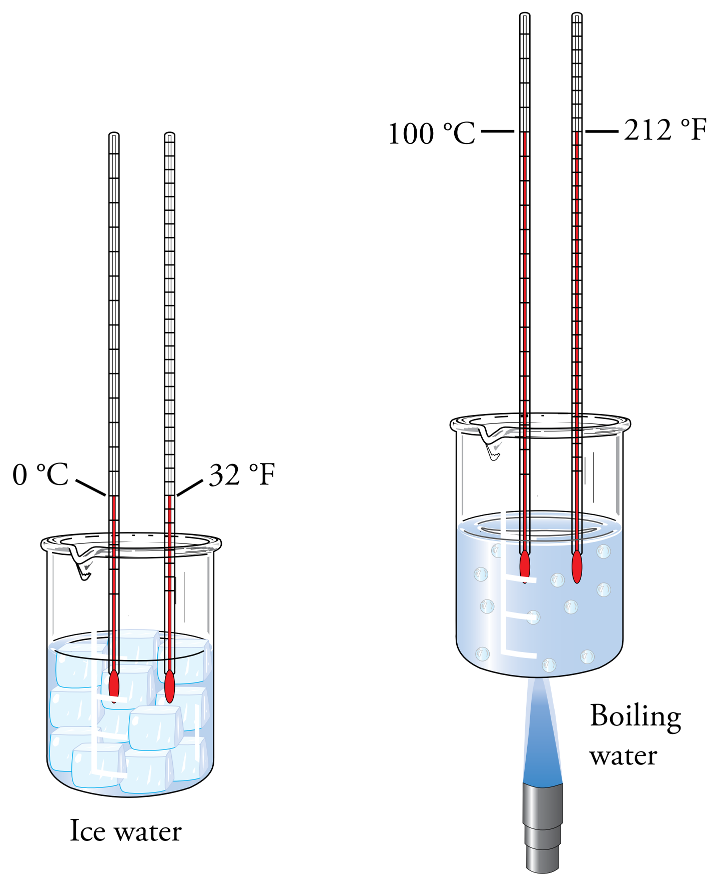
Objective 16

Thus a degree Fahrenheit is smaller than a degree Celsius. There are 180 °F per 100 °C, or 1.8 °F per 1 °C.

Figure 1.9 Celsius and Fahrenheit Thermometers

Objective 15

Objective 16



The thermometers that scientists use to measure temperature usually provide readings in degrees Celsius, but scientists usually convert Celsius values into Kelvin values to do calculations. The unit of measurement in the Kelvin scale is called the kelvin, K, (not "degree kelvin", just "kelvin"). The value 0 K is defined as **absolute zero**, the lowest possible temperature. Because the temperature of an object is a measure of the degree of motion of its particles, as the motion of the particles decreases, the temperature of the object decreases. Absolute zero is the point beyond which the motion of the

Objective 15

particles, and therefore the temperature, cannot be decreased. Absolute zero is 0 K, -273.15 °C, and -459.67 °F. Because the zero point for the Kelvin scale is absolute zero, all Kelvin temperatures are positive. The kelvin is defined so that its size is equal to the size of a degree Celsius.

Objective 16

Figure 1.10 summarizes the relationships between the three common temperature scales. In Chapter 2, we will use these relationships to convert measurements from one temperature scale to another.

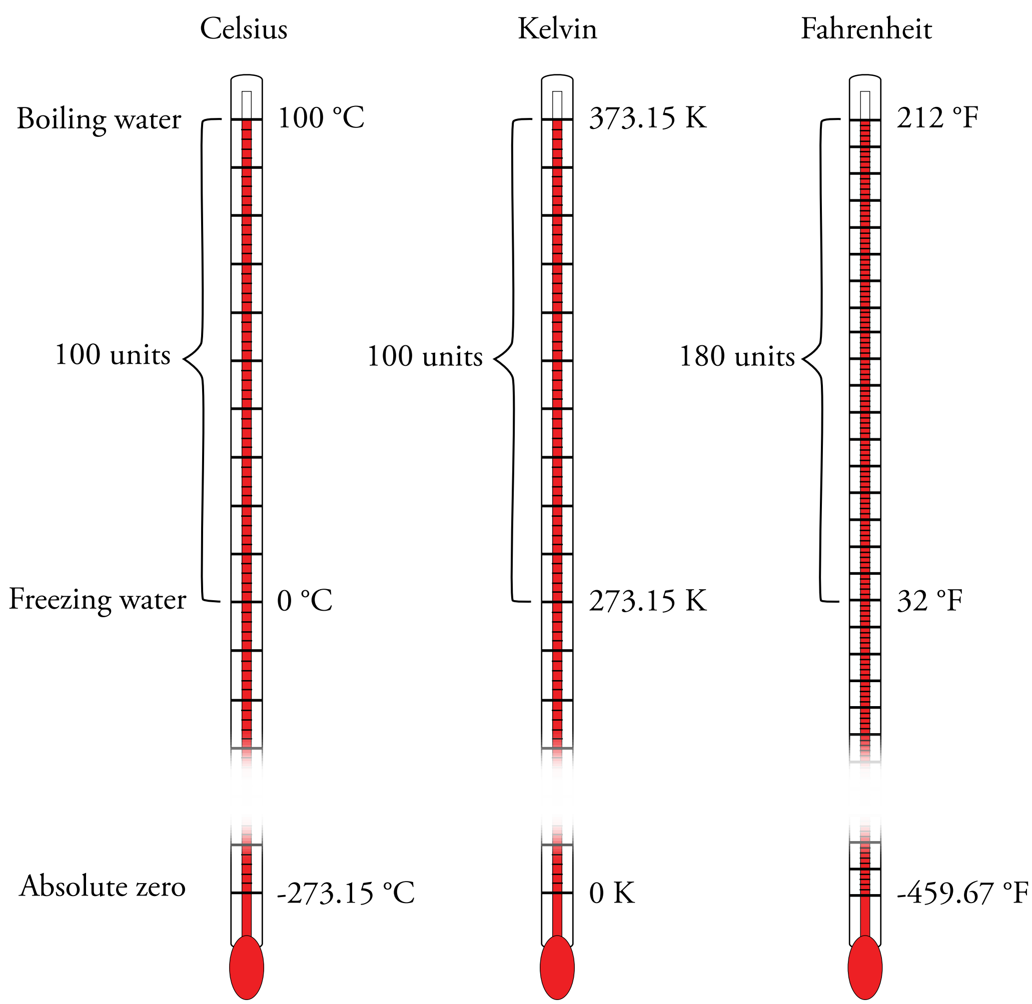


Figure 1.10 Comparing Temperature Scales

Objective 15 Objective 16

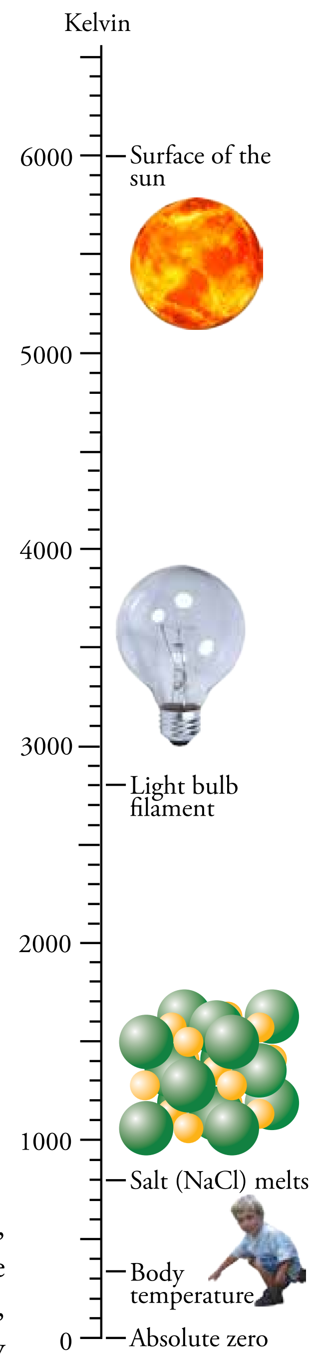


Figure 1.11 The Range of Temperatures

The highest temperatures in the universe are thought to be inside some stars, where theory predicts temperatures of about 10^9 K (a billion kelvins). Probably the hottest thing in your home is the tungsten filament in an incandescent light bulb, with a temperature of about 2800 K. Molten lava is about 2000 K. Normal body temperature is 310.2 K (98.6 °F or 37.0 °C). Normal room temperature is about 20 °C (68 °F or 293 K). The lowest temperature achieved in the laboratory is about 2×10^{-8} K (0.00000002 K). Figure 1.11 shows the range of temperatures.

1.5 Reporting Values from Measurements

All measurements are uncertain to some degree. Scientists are very careful to report the values of measurements in a way that not only shows the measurement's magnitude but also reflects its degree of uncertainty. Because the uncertainty of a measurement is related to both the *precision* and the *accuracy* of the measurement, we need to begin by explaining these terms.

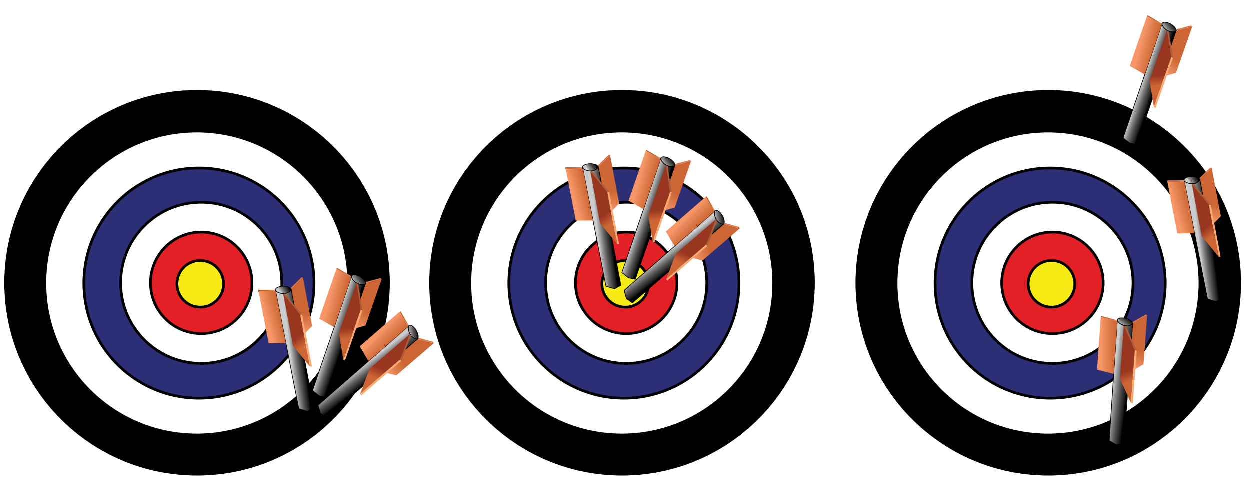
Accuracy and Precision

Precision describes how closely a series of measurements of the same object resemble each other. The closer the measurements are to each other, the more precise they are. The precision of a measurement is not necessarily equal to its accuracy. **Accuracy** describes how closely a measured value approaches the true value of the property.

Objective 17

To get a better understanding of these terms, let's imagine a penny that has a true mass of 2.525 g. If the penny is weighed by five different students, each using the same balance, the masses they report are likely to be slightly different. For example, the reported masses might be 2.680 g, 2.681 g, 2.680 g, 2.679 g, and 2.680 g. Because the range of values is ±0.001 g of 2.680 g, the precision of the balance used to weigh them is said to be ±0.001 g, but notice that none of the measured values is very accurate. Although the precision of our measurement is ±0.001 g, our measurement is inaccurate by 0.155 g (2.680 − 2.525 = 0.155). Scientists recognize that even very precise measurements are not necessarily accurate. Figure 1.12 provides another example of the difference between accuracy and precision.

Figure 1.12
Precision and Accuracy



This archer is precise but not accurate.

This archer is precise and accurate.

This archer is imprecise and inaccurate.

Describing Measurements

Certain standard practices and conventions make the taking and reporting of measurements more consistent. One of the conventions that scientists use for reporting measurements is to report all of the certain digits and one estimated (and thus uncertain) digit.

Objective 18

Consider, for example, how you might measure the volume of water shown in the graduated cylinder in Figure 1.13. (Liquids often climb a short distance up the walls of a glass container, so the surface of a liquid in a graduated cylinder is usually slightly curved. If you look from the side of the cylinder, this concave surface looks like a bubble. The surface is called a meniscus. Scientists follow the convention of using the bottom of the meniscus for their reading.) The graduated cylinder in Figure 1.13 has rings corresponding to milliliter values and smaller divisions corresponding to increments of 0.1 mL. When using these marks to read the volume of the liquid shown in Figure 1.13, we are certain that the volume is between 8.7 mL and 8.8 mL. By imagining that the smallest divisions are divided into 10 equal parts, we can estimate the hundredth position. Because the bottom of the meniscus seems to be about four-tenths of the distance between 8.7 mL and 8.8 mL, we report the value as 8.74 mL. Because we are somewhat uncertain about our estimation of the hundredth position, our value of 8.74 mL represents all of the certain digits and one uncertain digit.

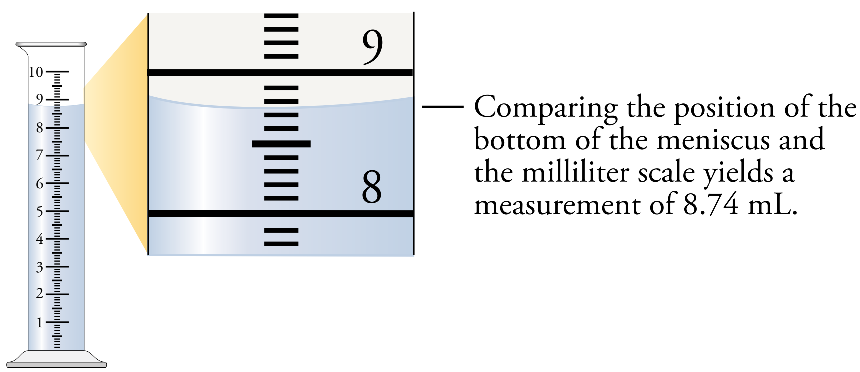


Figure 1.13
Measuring Volume with a Graduated Cylinder

Scientists agree to assume that the number in the last reported decimal place has an uncertainty of ±1 unless stated otherwise. Example 1.2 shows how this assumption is applied.

Objective 19

Example 1.2 – Uncertainty

Objective 19

If you are given the following values that are derived from measurements, what will you assume is the range of possible values that they represent?

a. 5.4 mL   c. 2.34×10^3 kg
b. 64 cm

Solution

We assume an uncertainty of ±1 in the last decimal place reported.

a. 5.4 mL means **5.4 ± 0.1 mL** or **5.3 to 5.5 mL.**
b. 64 cm means **64 ± 1 cm** or **63 to 65 cm.**
c. 2.34×10^3 kg means **$(2.34 \pm 0.01) \times 10^3$ kg** or **2.33×10^3 kg to 2.35×10^3 kg.**

Exercise 1.2 – Uncertainty

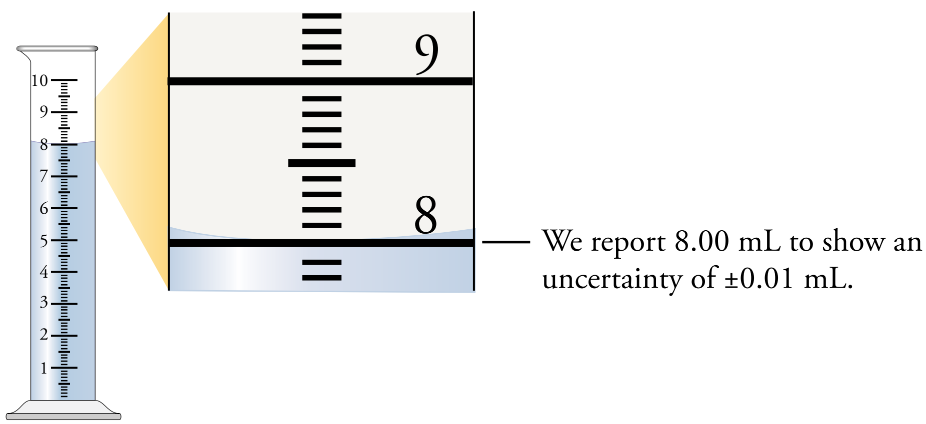
Objective 19

If you are given the following values that are derived from measurements, what will you assume is the range of possible values that they represent?

a. 72 mL
b. 8.23 m
c. 4.55×10^{-5} g

Sometimes it is necessary to use trailing zeros to show the uncertainty of a measurement. If the top of the liquid in the graduated cylinder shown in Figure 1.14 is right at the 8-mL mark, you would report the measurement as 8.00 mL to indicate that the uncertainty is in the second decimal place. Someone reading 8.00 mL would recognize that the measured amount was between 7.99 mL and 8.01 mL. Reporting 8 mL would suggest an uncertainty of ±1 mL, in which case the amount would be assumed to lie anywhere between 7 mL and 9 mL.

Figure 1.14
Reporting Values with Trailing Zeros



Objective 18

There are other ways to decide how to report values from measurements. For example, the manufacturer of the graduated cylinder in Figure 1.14 might inform you that the lines have been drawn with an accuracy of ±0.1 mL. Therefore, your uncertainty when measuring with this graduated cylinder will always be at least ±0.1 mL, and your values reported should be to the tenth position. In this case, the volumes in Figure 1.13 and 1.14 would be reported as 8.7 mL and 8.0 mL.

Objective 18

In general, though, unless you are told to do otherwise, the conventional practice in using instruments such as a graduated cylinder is to report all of your certain digits and one estimated digit. For example, if you were asked to measure the volumes shown in Figures 1.13 and 1.14, you would report 8.74 mL and 8.00 mL unless you were told to report your answer to the tenth place.

Example 1.3 - Uncertainty in Measurement

Objective 18

Consider a laboratory situation where five students are asked to measure the length of a piece of tape on a lab bench with a meter stick. The values reported are 61.94 cm, 62.01 cm, 62.12 cm, 61.98 cm, and 62.10 cm. The average of these values is 62.03 cm. How would you report the average measurement so as to communicate the uncertainty of the value?

Solution

If we compare the original measured values, we see that they vary in both the tenth and hundredth decimal places. Because we only report one uncertain decimal place, we report our answer as **62.0 cm**. The final zero must be reported to show that we are uncertain by ±0.1 cm. (When we also consider the uncertainties that arise from the difficulty in aligning the meter stick with the end of the tape and the difficulty estimating between the lines for the very tiny 0.1 cm divisions, it is reasonable to assume that our uncertainty is no better than ±0.1 cm.)

Exercise 1.3 - Uncertainty in Measurement

Objective 18

Let's assume that four members of your class are asked to measure the mass of a dime. The reported values are 2.302 g, 2.294 g, 2.312 g, and 2.296 g. The average of these values is 2.301 g. Considering the values reported and the level of care you expect beginning chemistry students to take with their measurements, how would you report the mass so as to communicate the uncertainty of the measurement?

Digital Readouts

The electronic balances found in most scientific laboratories have a digital readout that reports the mass of objects to many decimal positions. For example, Figure 1.15 shows the display of a typical electronic balance that reports values to the ten-thousandth of a gram, or to a tenth of a milligram. As you become more experienced, you will realize that you are not always justified in reporting a measurement to the number of positions shown on a digital readout. For the purposes of this course, however, if you are asked to make a measurement using an instrument that has a digital readout, you should report all of the digits on the display unless told to do otherwise.

Figure 1.15
The Display of a Typical Electronic Balance

Objective 18

Chapter Glossary

Chemistry The study of the structure and behavior of matter.

Value A number and unit that together represent the result of a measurement or calculation. The distance of a particular race, for example, may be reported as a value of *100 meters*.

Unit A defined quantity based on a standard. For example, in the value 100 meters, *meter* is the unit.

Base units The seven units from which all other units in the SI system of measurement are derived.

Mass The amount of matter in an object. Mass can also be defined as the property of matter that leads to gravitational attractions between objects and therefore gives rise to weight.

Weight A measure of the force of gravitational attraction between an object and a significantly large object, such as the earth or the moon.

Matter Anything that has mass and occupies space.

Absolute zero Zero kelvins (0 K), the lowest possible temperature, equivalent to −273.15 °C. It is the point beyond which motion can no longer be decreased.

Precision The closeness in value of a series of measurements of the same entity. The closer the values of the measurements, the more precise they are.

Accuracy How closely a measured value approaches the true value of a property.

You can test yourself on the glossary terms at the textbook's Web site.

Chapter Objectives

Notations in the text margins show where each objective is addressed in the chapter. If you do not understand an objective, or if you do not know how to meet it, find the objective number in the chapter body and reread the corresponding segment of text.

The goal of this chapter is to teach you to do the following.

1. Define all of the terms in the Chapter Glossary.

Section 1.3 The Scientific Method

2. Describe how science in general is done.

Section 1.4 Measurement and Units

3. Use the International System of Measurements (SI) base units and their abbreviations to describe length, mass, time, temperature, and volume.
4. Describe the relationship between liters and cubic meters.
5. State the numbers or fractions represented by the following metric prefixes, and write their abbreviations: giga, mega, kilo, centi, milli, micro, nano, and pico. (For example, kilo is 10^3 and is represented by k.)
6. Describe the relationships between the metric units that do not have prefixes (such as meter, gram, and liter) and units derived from them by the addition of prefixes. (For example, 1 km = 10^3 m.)

7. Given a metric unit, write its abbreviation; given an abbreviation, write the full name of the unit. (For example, the abbreviation for milligram is mg.)
8. Use everyday examples to describe the approximate size of a millimeter, a centimeter, a meter, and a kilometer.
9. Use everyday examples to describe the approximate size of a milliliter, a liter, and a cubic meter.
10. Describe the relationship between cubic centimeters and milliliters.
11. Describe the relationship between mass and weight.
12. Name the two factors that cause the weight of an object to change.
13. Use everyday examples to describe the approximate size of a gram, a kilogram, and a megagram.
14. Describe the relationships between metric tons, kilograms, and megagrams.
15. Describe the Celsius, Fahrenheit, and Kelvin temperature scales.
16. Describe the relationship between a degree Celsius, a degree Fahrenheit, and a kelvin.

Section 1.5 Reporting Values from Measurements

17. Given values for a series of measurements, state the precision of the measurements.
18. Report measured values so as to show their degree of uncertainty.
19. Given a value derived from a measurement, identify the range of possible values it represents based on the assumption that its uncertainty is ±1 in the last position reported. (For example, 8.0 mL says the value could be from 7.9 mL to 8.1 mL.)

Key Ideas

Complete the following statements by writing one of these words or phrases in each blank.

0 °C	kg
100 °C	magnitude
32 °F	m
212 °F	mass
accuracy	meter
applications	observation
base units	precision
Celsius	prefixes
certain	published
data	research
derive	research or experimentation
distance	second
estimated	standard
hypothesis	temperature
hypothesizing and testing	time
K	uncertain
kelvin	uncertainty
kilogram	

1. Complete this brief description of common steps in the development of scientific ideas: The process begins with _______________ and the collection of _______________. Next, scientists make an initial _______________. This leads to a more purposeful collection of information in the form of systematic _______________. The hypothesis is refined on the basis of the new information, and _______________ is designed to test the hypothesis. The results are _______________ so that other scientists might repeat the research and confirm or refute the conclusions. If other scientists confirm the results, the hypothesis becomes accepted in the scientific community. The next step of this scientific method is a search for useful _______________ of the new ideas. This often leads to another round of _______________ in order to refine the applications.
2. In the past, as measuring techniques became more precise and the demand for accuracy increased, the _______________ on which people based their units were improved.
3. The _______________, which has an abbreviation of _______________, is the accepted SI base unit for length.
4. The _______________, which has an abbreviation of _______________, is the accepted SI base unit for mass.
5. The _______________, which has an abbreviation of s, is the accepted SI base unit for _______________.
6. The kelvin, which has an abbreviation of _______________, is the accepted SI base unit for _______________.
7. Many properties cannot be described directly with one of the seven SI _______________. Rather than create new definitions for new units, we _______________ units from the units of meter, kilogram, second, kelvin, mole, ampere, and candela.

8. Because the SI base units (such as the meter) and derived units (such as the liter) are not always a convenient size for making measurements of interest to scientists, a way of deriving new units that are larger and smaller has been developed. Scientists attach _______________ to the base units, which have the effect of multiplying or dividing the base unit by a power of 10.
9. An object's weight on the surface of the earth depends on its _______________ and on the _______________ between it and the center of the earth.
10. For the Celsius scale, the temperature at which water freezes is defined as _______________, and the temperature at which water boils is defined as _______________. For the Fahrenheit scale, which is still commonly used in the United States, the temperature at which water freezes is defined as _______________, and the temperature at which water boils is defined as _______________.
11. The thermometers that scientists use to measure temperature generally provide readings in degrees _______________, but scientists usually convert these values into _______________ values to do calculations.
12. All measurements are _______________ to some degree. Scientists are very careful to report the values of measurements in a way that not only shows the measurement's _______________ but also reflects its degree of _______________. The uncertainty of a measurement is related to both the _______________ and the _______________ of the measuring instrument.
13. One of the conventions that scientists use for reporting measurements is to report all of the _______________ digits and one _______________ (and thus uncertain) digit.

Chapter Problems

Section 1.3 The Scientific Method

14. Describe how science in general is done. OBJECTIVE 2

Section 1.4 Measurement and Units

15. Complete the following table by writing the property being measured (mass, length, volume, or temperature) and either the name of the unit or its abbreviation. OBJECTIVE 3 OBJECTIVE 7

Unit	Type of measurement	Abbreviation	Unit	Type of measurement	Abbreviation
megagram			nanometer		
		mL			K

16. Complete the following table by writing the property being measured (mass, length, volume, or temperature), and either the name of the unit or its abbreviation. OBJECTIVE 3 OBJECTIVE 7

Unit	Type of measurement	Abbreviation	Unit	Type of measurement	Abbreviation
		GL	kilogram		
micrometer					°C

17. Convert the following ordinary numbers to scientific notation. (See Appendix B at the end of this text if you need help with this.)

a. 1,000
b. 1,000,000,000
c. 0.001
d. 0.000000001

18. Convert the following ordinary numbers to scientific notation. (See Appendix B at the end of this text if you need help with this.)

a. 10,000
b. 100
c. 0.0001
d. 0.01

19. Convert the following numbers expressed in scientific notation to ordinary numbers. (See Appendix B at the end of this text if you need help with this.)

a. 10^7
b. 10^{12}
c. 10^{-7}
d. 10^{-12}

20. Convert the following numbers expressed in scientific notation to ordinary numbers. (See Appendix B at the end of this text if you need help with this.)

a. 10^5
b. 10^6
c. 10^{-5}
d. 10^{-6}

Objective 6
Objective 10
Objective 14

21. Complete the following relationships between units.

a. _____ m = 1 km
b. _____ L = 1 mL
c. _____ g = 1 Mg
d. _____ cm^3 = 1 mL
e. _____ kg = 1 t (t = metric ton)

Objective 4
Objective 6
Objective 14

22. Complete the following relationships between units.

a. _____ g = 1 Gg
b. _____ L = 1 μL
c. _____ m = 1 nm
d. _____ L = 1 m^3
e. _____ Mg = 1 t (t = metric ton)

Objective 8

23. Would each of the following distances be closest to a millimeter, a centimeter, a meter, or a kilometer?
a. the width of a bookcase
b. the length of an ant
c. the width of the letter “t” in this phrase
d. the length of the Golden Gate Bridge in San Francisco

24. Which is larger, a kilometer or a mile?
25. Which is larger, a centimeter or an inch?
26. Which is larger, a meter or a yard?

Objective 9

27. Would the volume of each of the following be closest to a milliliter, a liter, or a cubic meter?
a. a vitamin tablet
b. a kitchen stove and oven
c. this book

28. Which is larger, a liter or a quart?

29. Which is larger, a milliliter or a fluid ounce?
30. Would the mass of each of the following be closest to a gram, a kilogram, or a metric ton? Objective 13
    a. a Volkswagen Beetle
    b. a Texas-style steak dinner
    c. a pinto bean
31. Explain the difference between mass and weight. Objective 11
32. Which is larger, a gram or an ounce?
33. Which is larger, a kilogram or a pound?
34. Which is larger, a metric ton or an English short ton? (There are 2000 pounds per English short ton.)
35. On July 4, 1997, after a 7-month trip, the Pathfinder spacecraft landed on Mars and released a small robot rover called Sojourner. The weight of an object on Mars is about 38% of the weight of the same object on Earth. Objective 12
    a. Explain why the weight of an object is less on Mars than on Earth.
    b. Describe the changes (if any) in the mass and in the weight of the rover Sojourner as the Pathfinder spacecraft moved from Earth to the surface of Mars. Explain your answer.
36. Which is larger, a degree Celsius or a degree Fahrenheit? Objective 16
37. How does a degree Celsius compare to a kelvin? Objective 16
38. Which is the smallest increase in temperature: 10 °C (such as from 100 °C to 110 °C), 10 K (such as from 100 K to 110 K), or 10 °F (such as from 100 °F to 110 °F)? Objective 16
39. Is the temperature around you now closer to 100 K, 200 K, or 300 K?

Section 1.5 Reporting Values from Measurements

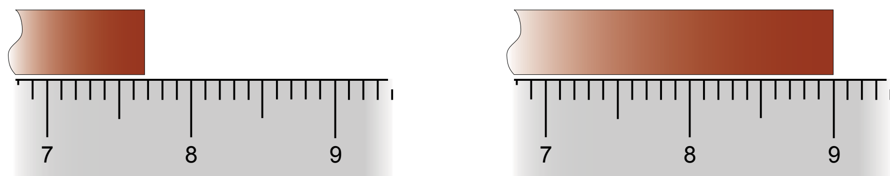
40. You find an old bathroom scale at a garage sale on your way home from getting a physical exam from your doctor. You step on the scale, and it reads 135 lb. You step off and step back on, and it reads 134 lb. You do this three more times and get readings of 135 lb, 136 lb, and 135 lb.
    a. What is the precision of this old bathroom scale? Would you consider this adequate precision for the type of measurement you are making? Objective 17
    b. The much more carefully constructed and better-maintained scale at the doctor's office reads 126 lb. Assuming that you are wearing the same clothes that you wore when the doctor weighed you, do you think the accuracy of the old bathroom scale is high or low?
41. Given the following values that are derived from measurements, what do you assume is the range of possible values that each represents? Objective 19
    a. 30.5 m (the length of a whale)
    b. 612 g (the mass of a basketball)
    c. 1.98 m (Michael Jordan's height)
    d. 9.1096×10^{-28} g (the mass of an electron)
    e. 1.5×10^{18} m^3 (the volume of the ocean)

Objective 19

42. If you are given the following values that come directly or indirectly from measurements, what will you assume is the range of possible values that they represent?
   a. 2.2 L (the volume of a basketball)
   b. 3 μm (the diameter of a hair)
   c. 2.0×10^{-6} nm (the diameter of a proton)
   d. 1.98×10^{5} kg (the mass of a whale)

Objective 18

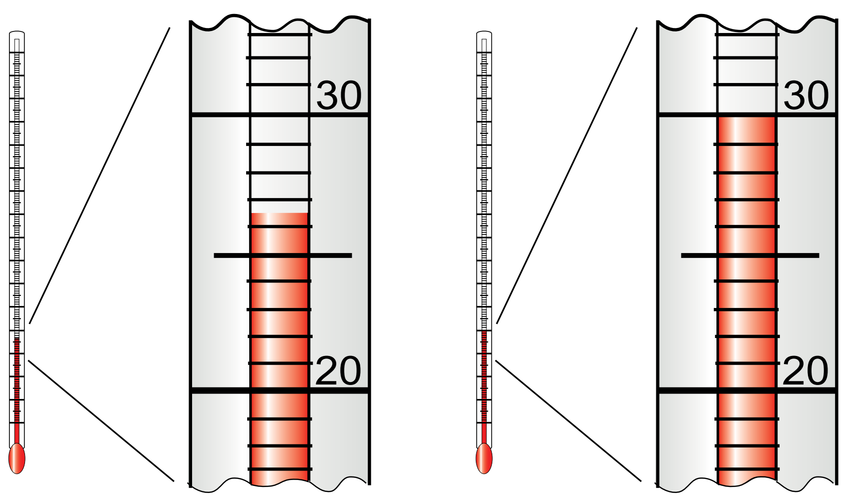
43. The accompanying drawings show portions of metric rulers on which the numbers correspond to centimeters. The dark bars represent the ends of objects being measured.



   a. If you were not given any specific instructions for reporting your values, what length would you record for each of these measurements?
   b. If you were told that the lines on the ruler are drawn accurately to ±0.1 cm, how would you report these two lengths?

Objective 18

44. The images below show a typical thermometer at two different temperatures. The units are degrees Celsius.



   a. If you were not given any specific instructions for reporting your values, what temperature would you record for each of these readings?
   b. If you were told that the lines on the thermometer are drawn accurately to ±1 °C, how would you report these two temperatures?

45. At a track meet, three different timers report the times for the winner of a 100-m sprint as 10.51 s, 10.32 s, and 10.43 s. The average is 10.42 s. How would you report the time of the sprinter in a way that reflects the uncertainty of the measurements? OBJECTIVE 18

46. Suppose that five students read a thermometer and reported temperatures of 86.6 °C, 86.8 °C, 86.6 °C, 86.8 °C, and 87.0 °C. The average of these values is 86.8 °C. How would you report this average to reflect its uncertainty? OBJECTIVE 18

47. The image below represents the digital display on a typical electronic balance. OBJECTIVE 19

a. If the reading represents the mass of a solid object that you carefully cleaned and dried and then handled without contaminating it, how would you report this mass?

b. Now assume that the reading is for a more casually handled sample of a liquid and its container. Let's assume not only that you were less careful with your procedure this time but also that the liquid is evaporating rapidly enough for the reading to be continually decreasing. In the amount of time that the container of liquid has been sitting on the pan of the balance, the mass reading has decreased by about 0.001 g. How would you report the mass?

Discussion Topic

48. Develop your own system of measurement for length, mass, and volume based on the objects in your immediate surroundings. Your system should have clearly defined units and abbreviations.

a. What unit could you use to measure the length of a desk?…the distance from here to the moon?…the diameter of an atom? What abbreviations could you use for each of these units?

b. What unit could you use to measure the mass of this book?…the mass of Godzilla?…the mass of a cat's whisker? What abbreviations could you use for each of these units?

c. What unit could you use to measure the volume of the water that a bathtub holds?…the volume of the planet Jupiter?…the volume of a pencil? What abbreviations could you use for each of these units?