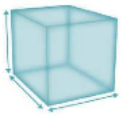
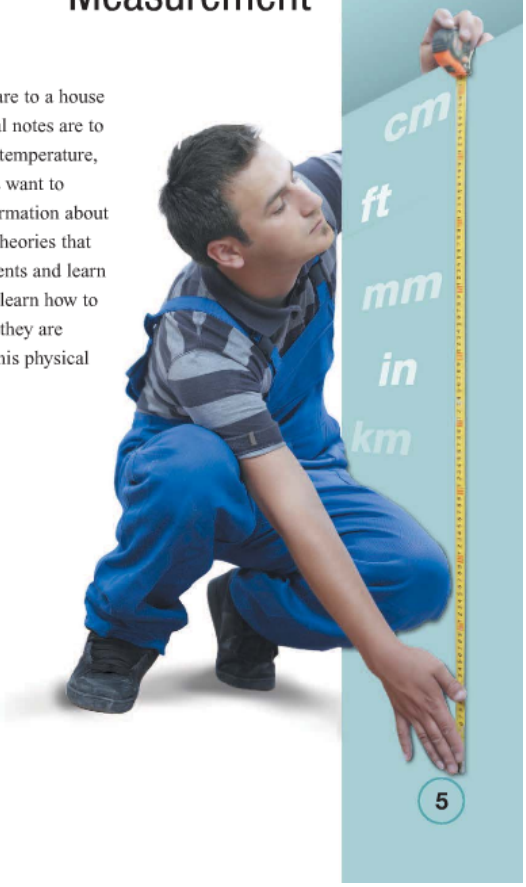
Chapter 1
Measurement



Measurement is to physical science what power tools are to a house builder, what clues are to a detective, and what musical notes are to a musician. Scientists measure dimensions, distances, temperature, mass, force, electrical current...the list could go on for pages. Scientists want to discover the natural laws of the universe. Measurements give them information about the world around them—reliable facts that form the basis of scientific theories that explain how the world works. In this chapter, you will make measurements and learn how to convert from one unit of measurement to another. You will also learn how to decide if one measurement is significantly different from another, or if they are essentially the same. These skills will be used many times throughout this physical science course as you collect data to learn how things work.

Key Questions

- ✔ *What is the SI system of measurement and how does it compare to the English system?*
- ✔ *What are two of the most important physical science quantities to measure?*
- ✔ *How do you decide how many digits to include in a measurement value?*



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Chapter 1 MEASUREMENT

1.1 Measurements

If you were to walk around Earth at the equator, you would have to walk approximately 40,075 kilometers, or almost 24,902 miles. How do kilometers and miles compare? Which is a longer distance: 1 kilometer, or 1 mile? Why do we talk about distance using two different units? Kilometers and miles are two common ways to describe distance, but scientists prefer to use kilometers. Read on to find out why.

VOCABULARY

measurement - a determination of the amount of something. A measurement has two parts: a value and a unit.

unit - a fixed amount of something, like a centimeter (cm) of distance.

Measurement and units

Measurements When studying physical science, you will make many measurements. Distance, time, mass, volume, weight, and temperature are just some of the quantities you will measure. A **measurement** is a determination of the amount of something. A measurement has two parts: a *number value* and a *unit* (Figure 1.1). For example, 2 meters (2 m) is a measurement because it has a number value, 2, and a unit, meters.

Units A **unit** is a standard amount that everyone agrees on. Without units, the numbers in a measurement don't make any sense. For example, if you asked someone to "walk 22," she would not know how far to go. Do you want her to walk 22 meters, 22 miles, or 22 centimeters (the height of this textbook)? If you say "walk 22 meters" then you have given her enough information because the unit "meters" tells her how to understand the quantity "22." An important rule of science is to *always include the correct units with number values*.

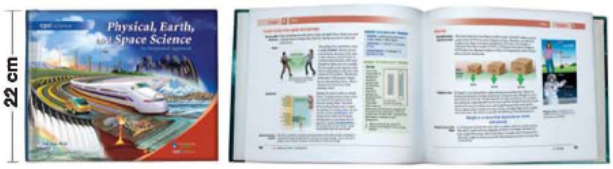


Figure 1.1: *A measurement includes a number value and a unit. Two meters is much taller than two feet!*

Two common measurement systems

English System of measurement

The **English System** is used for everyday measurements in the United States. Miles, yards, feet, inches, pounds, pints, quarts, gallons, cups, and teaspoons are all English System units. However, only one or two countries other than the United States still use this old system of measurement.

Measuring with SI units

During the 1800s, a new system of measurement—the Metric System—was developed in France and was quickly adopted by other European and South American countries. The goal of this system was for all units of measurement to be related, and for the units to form a base-10, or decimal, system. In 1960, the Metric System was revised and simplified, and a new name was adopted—International System of Units, or **SI** for short. The acronym SI comes from the French name *Le Système International d'Unités*. Today, the United States is the only industrialized nation that has not switched completely to SI.

Scientists use SI

Almost all fields of science worldwide use SI units because they are so much easier to work with. In the English system, there are 12 inches in a foot, 3 feet in a yard, and 5,280 feet in a mile. The relationship between these units is not easy to remember. In the metric system, there are 10 millimeters in a centimeter, 100 centimeters in a meter, and 1,000 meters in a kilometer. These factors of 10 are easier to remember and work with mathematically (Figure 1.2).

United States uses both systems

In the U.S., we use both English and SI units in our daily lives (Table 1.1). In many other countries, though, people use SI units for all measurements. Do you think the United States will ever use SI units for all measurements?

Table 1.1: Everyday SI Measurements Used in the United States

Measurement	Unit	Symbol	Usage
length	millimeter	mm	film, nails and screws, tools, pencil lead
length	meter	m	track and field sports, Olympic swimming pools
volume	liter	L	1- and 2-liter soda bottles
mass	milligram	mg	medication, nutrition labels
power	kilowatt	kW	electricity

VOCABULARY

English System - measurement system used for everyday measurements in the United States.

SI - International System of Units, used by most countries for everyday measurement and used by the scientific community worldwide.

Prefix	Meaning	Value
giga (G)	1 billion	1,000,000,000
mega (M)	1 million	1,000,000
kilo (k)	1 thousand	1,000
centi (c)	one-hundredth	0.01
milli (m)	one-thousandth	0.001
micro (μ)	one-millionth	0.000001

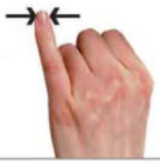
Figure 1.2: *SI prefixes and their values.*

Chapter 1 MEASUREMENT

The International System of Units (SI)

Units allow people to communicate amounts. To make sure their measurements are accurate, scientists use a set of standard units that have been agreed upon around the world. Table 1.2 shows the units in the International System of Units, or SI.

Table 1.2: The International System of Units (SI)

Measurement Approximations	Unit	Comparison with Standard
LENGTH width of little finger = 1 cm 	**meter (m)** kilometer (km) decimeter (dm) centimeter (cm) millimeter (mm) micrometer (μm) nanometer (nm)	 1 km = 1,000 m 1 dm = 0.1 m 1 cm = 0.01 m 1 mm = 0.001 m 1 μm = 0.000001 m 1 nm = 0.000000001 m
VOLUME 10 drops of water = 1 mL 	**cubic meter (m^3)** cubic centimeter (cm^3) liter (L) milliliter (mL)	 1 cm^3 = 0.000001 m^3 1 L = 0.001 m^3 1 mL = 0.000001 m^3
MASS 1 large paperclip = 1 gram 	**kilogram (kg)** gram (g) milligram (mg)	 1 g = 0.001 kg 1 mg = 0.000001 kg
 **TEMPERATURE** 21°C = room temperature	Kelvin (K) Celsius (°C)	0°C = 273 K 100°C = 373 K

STUDY SKILLS

Learn to Think SI

How long is a centimeter? How heavy is a gram? How much is a milliliter? The easy way to "think SI" is to remember some simple measurements. Take a look at the pictures in the table at the left, and see if you can remember them.

1. 1 cm is about the width of your little finger.
2. 1 mL is about the same volume as 10 drops of water.
3. 1 g is about the mass of one large paperclip.
4. 21 °C is a comfortable room temperature.

Learning to think SI is like learning a new language; the more practice you have, the easier it is to understand.

Bytes and SI prefixes

A byte is a unit of computer data storage. When you add SI prefixes to any unit, you change the size of the unit, as you can see in the chart below and in Figure 1.3. It's difficult to imagine a quantity as large as one quadrillion! One quadrillion bytes equals 1,000 trillion—that's a petabyte.

SI Prefixes for Decimal Multiples

Number	Factor	Name	Symbol
1 000 000 000 000 000	10^{15}	peta	P
1 000 000 000 000	10^{12}	tera	T
1 000 000 000	10^{9}	giga	G
1 000 000	10^{6}	mega	M
1 000	10^{3}	kilo	k
100	10^{2}	hecto	h
10	10^{1}	deca	da
0.1	10^{-1}	deci	d
0.01	10^{-2}	centi	c
0.001	10^{-3}	milli	m
0.000 001	10^{-6}	micro	μ
0.000 000 001	10^{-9}	nano	n
0.000 000 000 001	10^{-12}	pico	p

Figure 1.3: *Use these prefixes on any SI unit to change its size. A nanometer is one billion times smaller than a meter!*

Accuracy, precision, and resolution

Accuracy The words *accuracy* and *precision* have special meanings in science that are a little different from how people use these words in daily conversation (Figure 1.4). **Accuracy** is how close a measurement is to the true value. An accurate clock or watch will give a time reading that is the same as or extremely close to the official time from a government standard. An accurate golf putt is one that falls in the hole. A very accurate golf drive would be a hole-in-one.

Precision Precision does not have the same meaning as accuracy. **Precision** describes how close together repeated measurements or events are to one another. Precise clocks throughout a school would all read the same time at any given moment. School clocks can be precise without being accurate. Can you explain how this could be true? If I hit three different golf balls off the same tee, and each one of them goes into the same sand trap, I have good precision but poor accuracy.

Resolution **Resolution** is another important term to understand when you are working with measured quantities. Resolution refers to the smallest interval that can be measured (Figure 1.4). The resolution of a centimeter ruler is 0.5 mm. This is because, if you look closely, you can tell if a measurement falls right on a millimeter mark, or between millimeter marks. The resolution on most classroom clocks is 0.5 second. Without a second hand, the resolution of a clock would be only 0.5 minute.

Resolution in images The word *resolution* often appears in connection with digital cameras or high definition (HD) TV. A high-resolution image is very sharp and high quality. For example, an HDTV image has 1,980 dots in the horizontal direction. A standard TV image has only 640 dots. A feature that is two dots wide in an HDTV image is just a blur on a standard TV. You can think of resolution as the "sharpness" of a measurement. A measurement with lots of resolution is a very "sharp" measurement. A timer that measures seconds to four decimal places has a resolution of one ten-thousandth of a second. A stopwatch that measures seconds to two decimal places has a lower resolution of one-hundredth of a second.

VOCABULARY

accuracy - how close a measurement is to an accepted or true value.

precision - describes how close together or reproducible repeated measurements are.

resolution - refers to the smallest interval that can be measured.

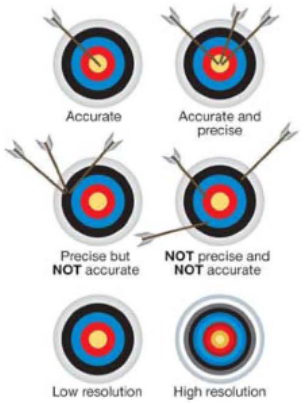


Figure 1.4: *Accuracy, precision, and resolution.*

Section 1.1 Review

1. Explain, using your own example, why you must always give a unit when reporting a measurement.
2. Tell two reasons why SI is easier to use than the English System.
3. An external computer flash drive can hold 1 gigabyte of data. How many bytes is this?
4. Which is larger: a megawatt or a kilowatt? How many times larger is it?
5. Put these units in order from smallest to largest: decimeter, meter, kilometer, millimeter, centimeter, nanometer, micrometer.
6. Your friend asks you for a glass of water and you bring her 5 milliliters of water. Is this more or less than what she was probably expecting? Explain your reasoning.
7. The length of a sheet of U.S. standard (letter size) paper is closest to:
   a. 8 centimeters
   b. 11 centimeters
   c. 29 centimeters
   d. 300 centimeters
8. A nickel has a mass of about:
   a. 0.1 gram
   b. 5 grams
   c. 50 grams
   d. 100 grams
9. Why do you suppose the United States still uses the English System for everyday measurements, while almost every other country uses SI? Give several possible reasons.
10. Refer to Figure 1.5 to answer these questions:
    a. What is the resolution of the stopwatch?
    b. Time measurements from a stopwatch are not very precise. Why not?

CHALLENGE

Everyday English and SI Units

How many different ways are English and SI units used to measure everyday things in the United States? Speed is measured in miles per hour (mph). Is that an English or SI unit? Is gasoline sold in English or SI units? What is that unit? Following is a list of things that are commonly measured. Make a chart that shows what unit is most commonly used to measure each thing in the United States, and show whether that unit belongs to the English System or SI. You might be surprised at how much we use BOTH systems!

- gasoline
- road map distances
- aspirin/pain reliever tablets
- mechanical pencil lead
- skis
- milk
- large soda bottles
- electricity
- body weight
- mountain bike size
- racing bike size

Figure 1.5: *Question 10.*