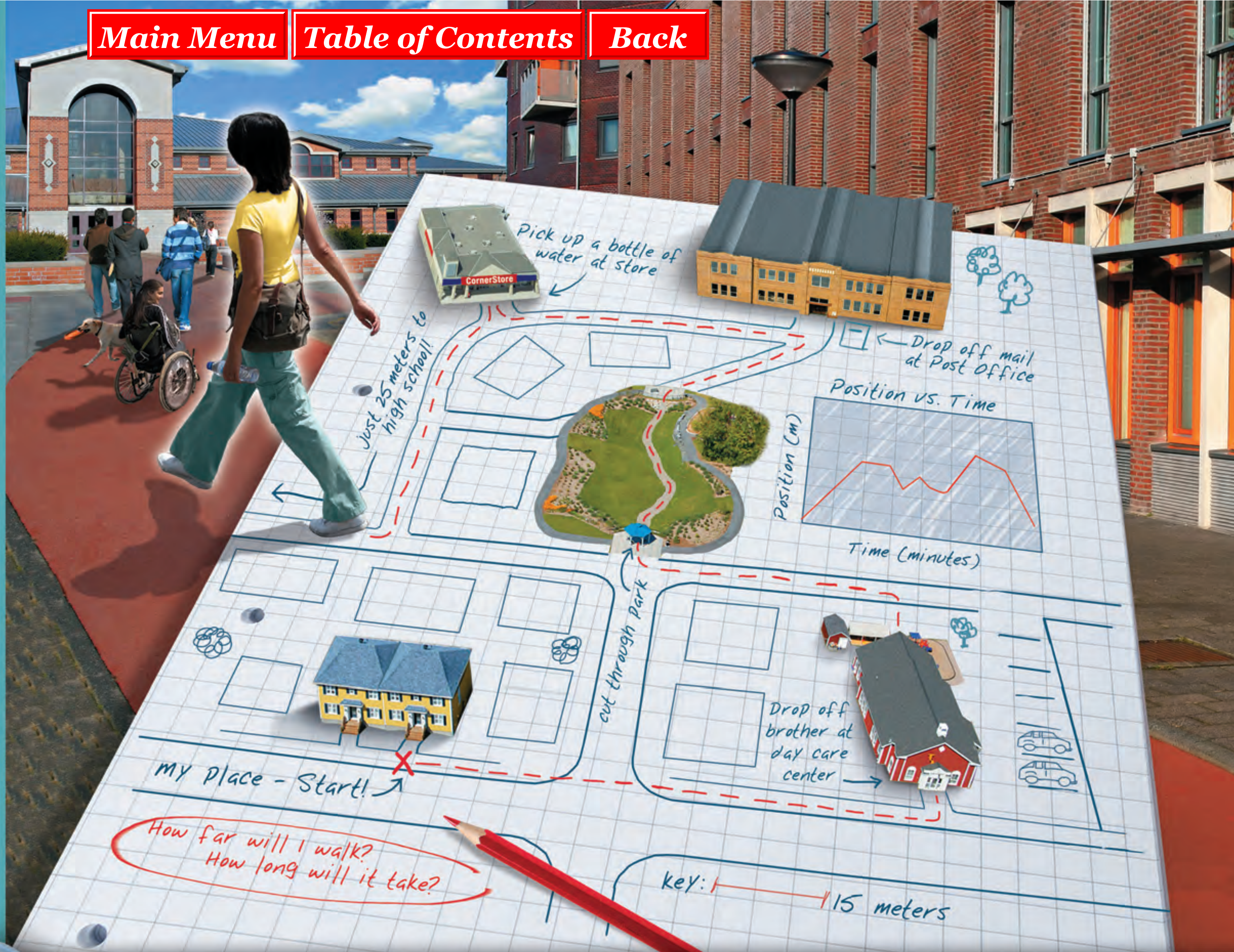
Unit 1

Science and Measurement



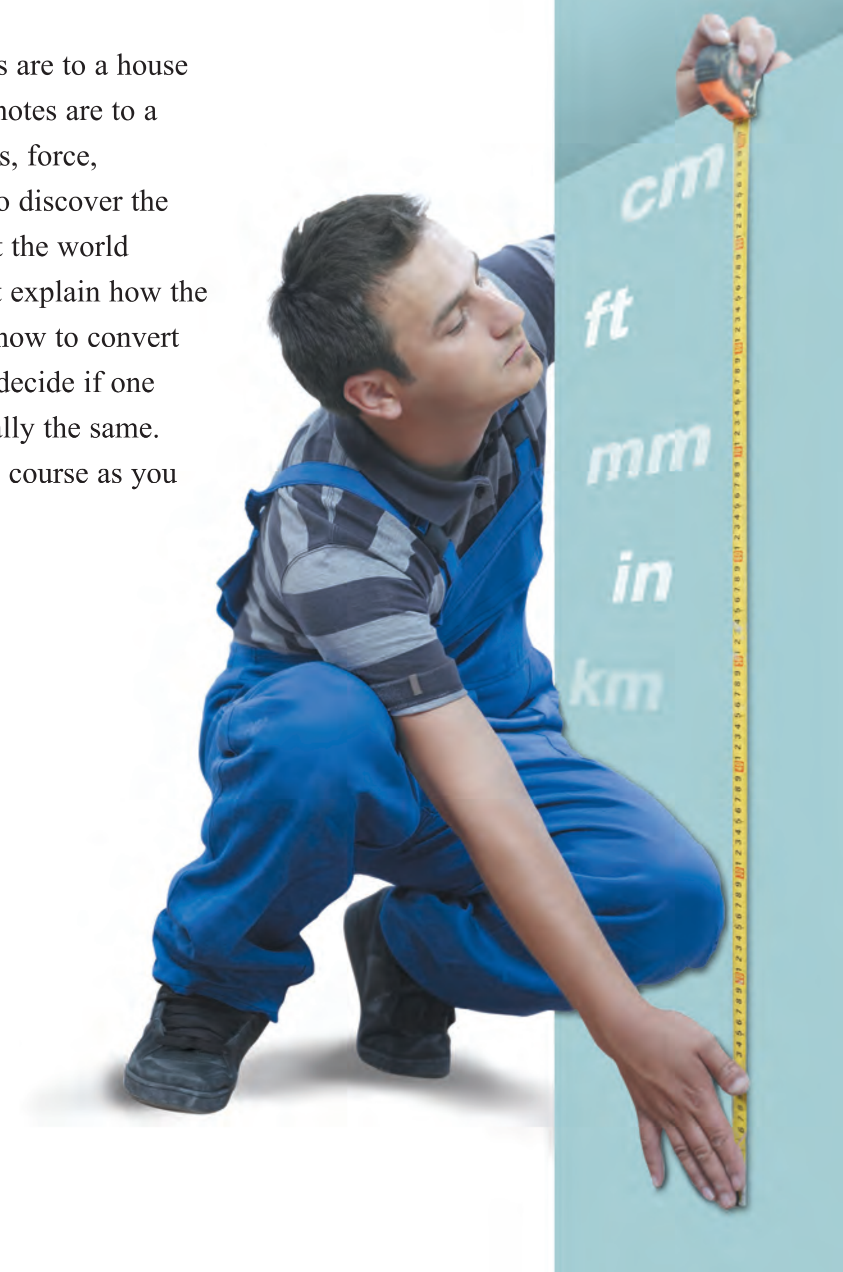
Try this at home

Does a 1-cup dry measuring cup hold the same amount as a 1-cup liquid measuring cup? Fill a 1-cup measuring cup that is meant to be used for dry cooking ingredients with water. Pour the water into a plastic cup and mark the water level, then discard the water (use it to water a plant!). Now measure out 1 cup of water in a liquid measuring cup. Pour this into the plastic cup and mark the level. How do the amounts compare? Why should scientists use a standardized system of measurement?

Chapter 1

Measurement

Measurement is to physical science what power tools are to a house builder; what clues are to a detective; what musical notes are to a musician. Scientists measure dimensions, distances, temperature, mass, force, electrical current, and the list could go on for pages. Scientists want to discover the natural laws of the universe. Measurements give us information about the world around us—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 it is 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?*

1.1 Measurements

A rocket must reach a speed of over 40,000 kilometers per hour to break free from Earth's gravity and get into space. The rocket has to travel very fast—it covers about 7 miles each *second*! How do kilometers and miles compare? Which is a longer distance: one kilometer, or one mile? The answer is one mile, but why do we talk about distance in 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. Typically 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 2* feet*!*

SC.912.N.1.2-Describe and explain what characterizes science and its methods.
MA.912.S.1.2-Determine appropriate and consistent standards of measurement for the data to be collected in a survey or experiment.

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. These are not easy numbers 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. Factors of 10 are easier to remember and work with mathematically than 12, 3, and 5,280 (Figure 1.2).

United States uses both systems

Did you know that you use both English and SI units in your daily life? In many other countries, 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 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	Number
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

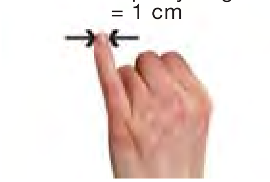
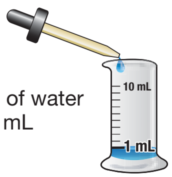
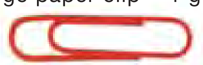
Figure 1.2: *SI prefixes.*

MA.912.S.1.2-Determine appropriate and consistent standards of measurement for the data to be collected in a survey or experiment.

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, known as SI.

Table 1.2: Common SI Units

Measurement Approximations	Unit	Value
Length width of pinky 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 paper clip = 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 1 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.

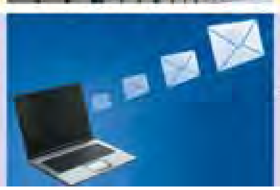
1. 1 cm is about the width of your little finger.
2. 1 mL is about the same volume as 10 drops of water.
3. 1 g is about the mass of one large paperclip.
4. 21 degrees Celsius is a comfortable room temperature.

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

MA.912.S.1.2-Determine appropriate and consistent standards of measurement for the data to be collected in a survey or experiment.

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.

BYTE One unit of computer storage		8 bits		1 character = anything you type on a keyboard
KILOBYTE One thousand bytes		1/2 page of text		One computer onboard *Apollo* (1969) = 74 KB of memory
MEGABYTE One million bytes		One minute of music		500 pages of text
GIGABYTE One billion bytes		18 hours of mp3 music		12 hours of flash video
TERABYTE One trillion bytes		Library of Congress has about 10 TB of print collections		Superstore data warehouse has about 9,000 TB of data
PETABYTE One quadrillion bytes		Internet search engine processes 20 PB per day		All emails sent in the world in 2002 = 440 PB

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!*

Section 1.1 Review

1. Explain, using your own example, why you must always give a unit when reporting a measurement.
2. Draw two columns on your paper. Label the first column *SI* and the second column *English System*. Sort this list and write the units in the correct column: inch, centimeter, yard, teaspoon, milliliter, bushel, gallon, liter, mile, gram, quart, pint, kilometer, pound.
3. Explain two reasons why SI is easier to use than the English System.
4. An external computer flash drive can hold 1 gigabyte of data. How many bytes is this?
5. Which is larger: a megawatt or a kilowatt? How many times larger is it?
6. Put these units in order from smallest to largest: decimeter, meter, kilometer, millimeter, centimeter, nanometer, micrometer.
7. 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.
8. 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
9. A nickel weighs about:
   a. 0.1 gram
   b. 5 grams
   c. 50 grams
   d. 100 grams
10. 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.

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? Here 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 may be surprised at how much we use *both* systems!

- gasoline
- road map distances
- aspirin/pain reliever tablets
- camera film
- mechanical pencil lead
- skis
- milk
- large soda bottles
- electricity
- time
- body weight

1.2 Time and Distance

Measurement is a key skill and concept in physical science. In this section, you will learn about measuring two fundamental properties of the universe: time and distance.

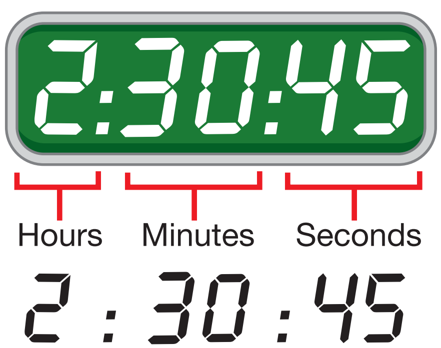
Time

Time in science We often want to know how things change over time. For example, a car rolls down a hill over time. A hot cup of coffee cools down over time. The laws of physical science tell us how things change over time.

What time is it? Time is used two ways (Figure 1.4). One way is to identify a particular moment in the past or in the future. For example, saying your 18th birthday party will be on January 1, 2011, at 2:00 p.m. identifies a particular moment in the future for your party to start. This is the way “time” is usually used in everyday conversation.

How much time? The second way is to describe a *quantity* of time. The question “How much time?” is asking for a quantity of time. A quantity of time is also called a *time interval*. Any calculation involving time that you do in physical science will always use time intervals, *not* time of day.

Time in seconds



Many problems in science use time in seconds. For calculations, you may need to convert hours and minutes into seconds. For example, the timer (left) shows 2 hours, 30 minutes, and 45 seconds.

How many total seconds does this time interval represent? There are 60 seconds in a minute, so multiply 30 minutes by 60 to get 1,800 seconds. There are 3,600 seconds in an hour, so multiply 2 hours by 3,600 to get 7,200 seconds. Add up all the seconds to get your answer: 45 + 1,800 + 7,200 = 9,045 seconds.

Figure 1.4: *There are two different ways to understand time.*

CHALLENGE

What is your reaction time?

Sit at a table and rest your arm on the table, with your hand hanging off the edge. Have a friend dangle a metric ruler just above your thumb and index finger. When your friend drops the ruler, catch it quickly between your thumb and finger. Record the centimeter mark where you caught the ruler. Approximate reaction times are: 0.10 seconds for 5 cm, 0.14 s for 10 cm, 0.18 s for 15 cm, 0.20 s for 20 cm, 0.23 s for 25 cm, and 0.25 s for 30 cm.

Do several trials and discuss.

Distance

What is distance?

Distance is the amount of space between two points (Figure 1.5). You can also think of distance as how far apart two objects are. You probably have a good understanding of distance from everyday experiences, like the distance from your house to school, or the distance between your city and the next town. The concept of distance in physics is the same, but the actual distances may be much larger or much smaller than anything you measure in everyday life.

Distance is measured in units of length

Distance is measured in units of **length**. The English System uses inches, feet, yards, and miles for length units. One foot equals 12 inches. Do you know how many feet are in a yard? There are three feet in a yard. How many yards are in a mile? There are 1,760 yards in a mile. Did you know those answers? These numbers are not easy to remember. The SI units of length are much easier to use, because they are based on powers of 10, and the prefixes tell you something about the unit value. For example, the prefix *centi-* means one hundredth, so you know that a centimeter is 100 times smaller than a meter. There are 100 centimeters in a meter. The unit "inch" does not tell you anything about how it is related to a foot. There are 12 inches in a foot, but you wouldn't know that from the unit name!

SI distance unit

The **meter** is a basic SI distance unit. In 1791, a meter was defined as one ten-millionth of the distance from the North Pole to the equator. Today a meter is defined more accurately using the speed of light (Figure 1.6). The meter was used as a starting point for developing the other SI units.

Useful prefixes

Prefixes are added to the names of basic SI units. Prefixes describe very small or very large measurements. There are many SI unit prefixes, but these three are commonly used with meters to measure distance.

Prefix	Prefix + meter	Compared to 1 Meter
kilo-	**kilometer**	**1,000 times bigger**
centi-	**centimeter**	**100 times smaller**
milli-	**millimeter**	**1,000 times smaller**

VOCABULARY

distance - the amount of space between two points.

length - a measured distance.

meter - a basic SI unit of length.

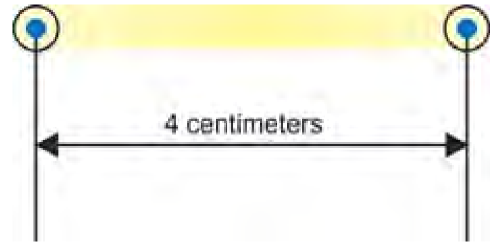


Figure 1.5: *Distance is the amount of space between two points.*

Figure 1.6: *In 1791, a meter was defined as 1/10,000,000 of the distance from Earth's North Pole to the equator. Today, a meter is defined more accurately as the distance that light travels in a fraction of a second.*

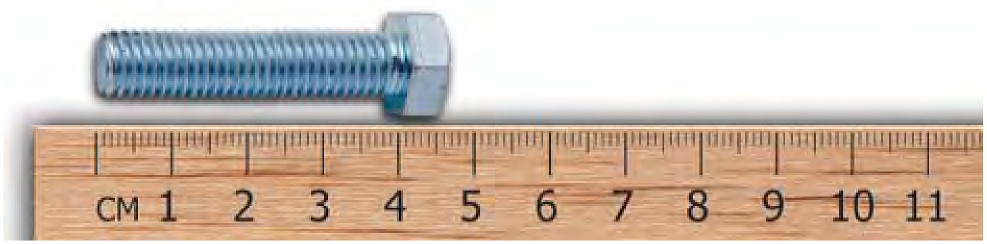
MA.912.S.1.2-Determine appropriate and consistent standards of measurement for the data to be collected in a survey or experiment.

The meter stick

A meter stick is a good tool to use for measuring ordinary lengths in the laboratory. A meter stick is 1 meter long and is divided into millimeters and centimeters. Figure 1.7 shows a meter stick next to objects of different lengths. Can you see how the meter stick is used to measure the length shown for each object?

Using a centimeter ruler

Using a meter stick or a centimeter ruler to make distance or length measurements is easy. Each centimeter is divided into 10 smaller units, called millimeters. Try using the centimeter rulers below to find the measurement of the length each object. Don't peek at the answers!



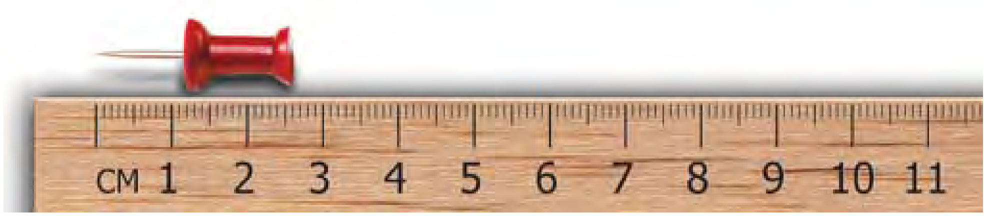


Figure 1.7: *Reading a meter stick.*

Solve first Look later

The measurements are:

bolt: 4.70 cm

pencil: 7.90 cm

pushpin: 2.60 cm

Section 1.2 Review

1. What are two different ways to understand time? Explain and give examples.
2. How many minutes are there in 1.5 hours? Don't forget to show your work!
3. Convert 330 minutes to hours, and show your work.
4. Men in the age group of 18–34 years need to be able to run a marathon in 3 hours and 10 minutes to qualify for the Boston Marathon. How many seconds is this? Show your work!
5. Study the table in Figure 1.8 to answer the following questions.
   a. Which movies are longer than 2 hours?
   b. Which (if any) movies are longer than 3 hours?
   c. Convert the running time of *Gone With the Wind* to hours and minutes.
   d. Does any movie have a running time of less than 1.5 hours? If so, which one(s)?
6. Your teacher says, "There are 100 centimeters in a meter, and this fact is revealed in the unit's name (centimeter). There are 3 feet in one yard, but this fact is not revealed in the unit's name (yard)." Explain what your teacher means by this.
7. Which is larger? Copy each pair of units and circle the one that is the largest quantity for each pair.
   a. 1 centimeter or 1 meter
   b. 1 millimeter or 1 centimeter
   c. 1 kilometer or 1 meter
8. Which is larger? Copy each pair of measurements and circle the length that is the longest for each pair.
   a. 42 mm or 10 cm
   b. 15 mm or 0.15 cm
   c. 10 mm or 2 cm

Movie	Running Time (min)
Casablanca	102
Citizen Kane	119
Gone with the Wind	222
E.T. the Extraterrestrial	115
Jaws	124
King Kong (2005)	188
Titanic (1997)	194
Back to the Future	116

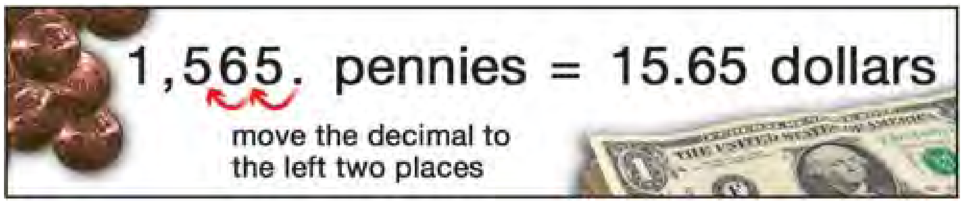
Figure 1.8: *Question 5.*

1.3 Converting Units

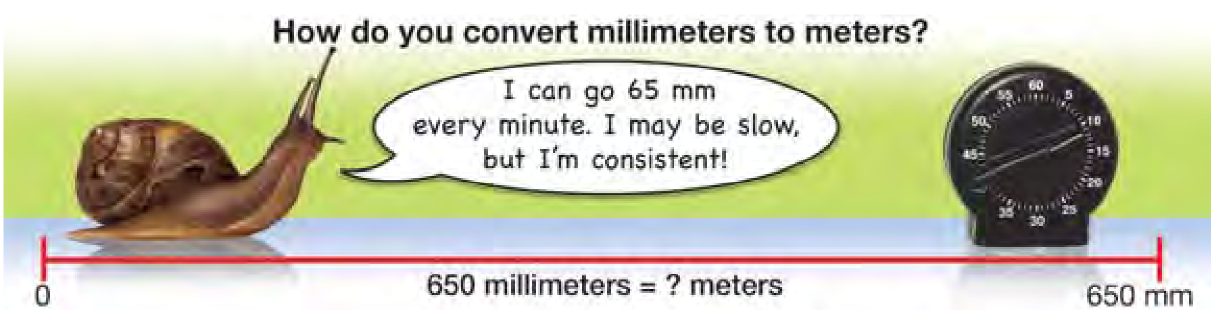
When describing the length of a ski, you could say that it is 150 centimeters or 1.5 meters. The ski length is the same—the only thing that is different is the measurement unit. Unit conversion is an important skill in the language of measurement.

Why convert?

What does it mean to "convert"? Suppose you empty your coin bank and count out 1,565 pennies. You probably would rather think of that quantity of money in dollars. How do you figure out how many dollars you have? Well, you convert the 1,565 cents to the dollar amount. Since there are 100 pennies in a dollar, you divide 1,565 by 100. This is the same as moving the decimal point two places to the left. 1,565 pennies and 15.65 dollars represent the same amount of money.



Converting SI units Converting SI units is just as easy as converting pennies to dollars. Suppose a snail can travel about 65 millimeters in one minute. In 10 minutes it can go 10 times as far (65 × 10) or 650 mm. It's hard to visualize 650 mm. You know that a meter stick is relatively close in size to a yard stick, which you are familiar with. If you convert millimeters to meters, you might be able to better visualize how far the snail can travel in 10 minutes.



CHALLENGE

SI Estimation Challenge

For each item below, only one measurement in the list is realistic. The other two measurements are wildly wrong. Can you choose the realistic measurement for each item?

1. width of a postage stamp: 1 m, 15 cm, or 20 mm
2. thickness of a CD: 0.1 m, 0.01 m, or 0.001 m
3. height of a bus: 152.4 mm, 2.0 m, or 250 cm
4. length of an inchworm: 25.4 mm, 25.4 cm, or 0.254 m
5. length of a football field: 91.44 m, 200 m, or 1 km

MA.912.S.1.2-Determine appropriate and consistent standards of measurement for the data to be collected in a survey or experiment.

Solving Problems: Converting SI Units

When you convert from one SI unit to another, you multiply or divide by a series of tens. This conversion tool will help you move the decimal point.

Convert 650 millimeters to meters.

1. Looking for: You are asked for the distance in meters.

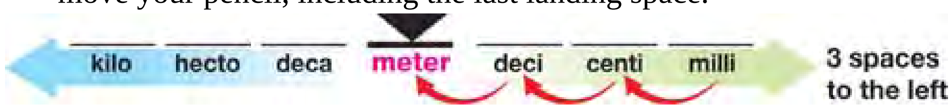
2. Given: You are given the distance in millimeters.

3. Relationships: There are 1,000 millimeters in 1 meter.

4. Solution:

1. Find the millimeter place, and put your pencil on that space.

2. Move your pencil to the meters place, and count how many spaces you move your pencil, including the last landing space.



3. Now move the decimal point in 650 to the left 3 places.

650 mm = 0.650 m

Your turn...

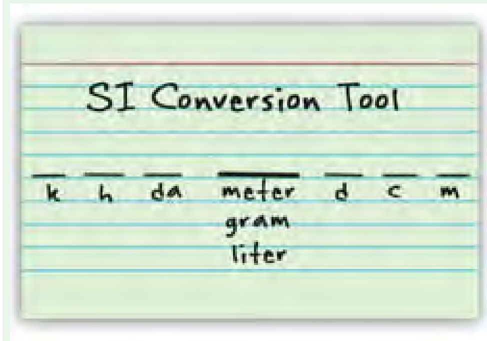
a. Convert 142 kilometers to meters.

b. Convert 754,000 centimeters to kilometers.

STUDY SKILLS

SI Conversion Tool

Copy this SI place value table on an index card so you can refer to it whenever you have to convert SI units. The table will tell you how many places to move the decimal point, and in what direction to move it.



Solve first Look later

a. 142,000 m

b. 7.54 km

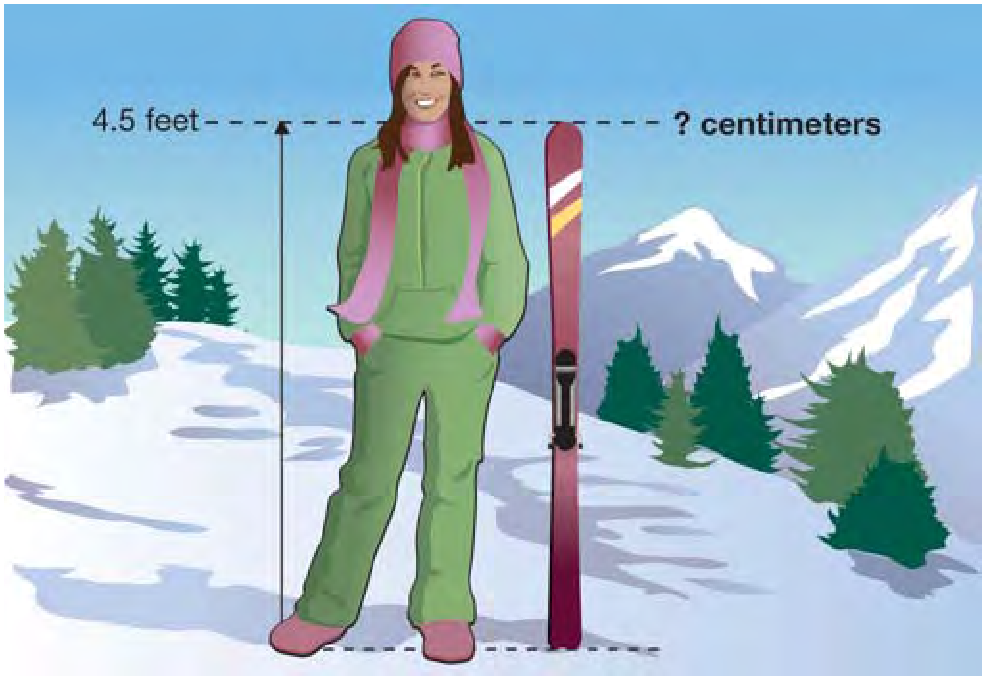
Converting between English and SI units

The problem of multiple units

It would be nice if everyone always used the same unit for length, like the meter. Unfortunately, many different units of length are used for different things, and in different places. In the United States, you will find inches, feet, and miles used more commonly than centimeters, meters, and kilometers. Sometimes you will need to covert from English to SI units.

Comparing English and SI units

Downhill skis come in many different centimeter lengths. If you stand a ski up next to you, the ski should come up as high as your chin. Suppose the distance from your toes to chin is 4.5 feet. What length skis should you buy, in centimeters? To answer the question you need to convert from feet to centimeters. To do the conversion you multiply 4.5 feet by a **conversion factor.** A conversion factor is a ratio that has the value of one. Study the problem solving steps on the next page to see how to set up a conversion using conversion factors. This method of converting units is called **dimensional analysis**.



VOCABULARY

conversion factor - a ratio that has a value of one, and is used when setting up a unit conversion problem.

dimensional analysis - a method of using conversion factors and unit canceling to solve a unit conversion problem.

SCIENCE FACT

English and SI Units

Suppose you are working on your bicycle and the wrench you select is one size too small. The illustration below shows that it is easier to choose the next bigger size if you use SI units.

MA.912.S.1.2-Determine appropriate and consistent standards of measurement for the data to be collected in a survey or experiment.
SC.912.N.1.2-Describe and explain what characterizes science and its methods.

Solving Problems: Converting Units

Convert 4.5 feet to centimeters.

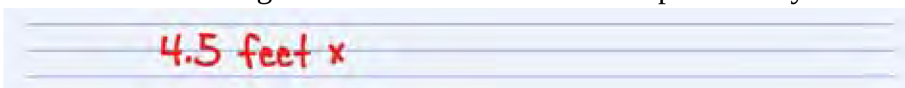
1. Looking for: You are asked for a length in centimeters.

2. Given: You are given the length in feet.

3. Relationships: There are 30.48 cm in one foot (you can look this up in a conversion table).

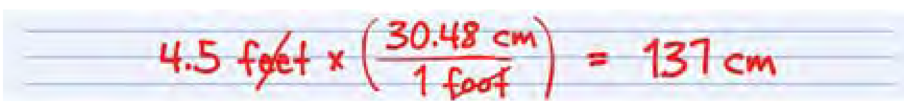
4. Solution:

1. Write down the given measurement and a multiplication symbol.



2. Create a conversion factor by drawing a fraction bar and copying the given unit (feet) into the bottom of the fraction. Next, put the unit you are looking for in the numerator (cm). Put the number "1" next to the larger unit (foot) and for the smaller unit, write down how many of them equal 1 of the larger unit (30.48 cm).

3. Cancel like units in the problem setup. This is how you keep track of how well your dimensional analysis setup is working. Your goal is to cancel all units except the one you are solving for (cm).



4. Now you are ready to do the math! This problem setup tells you to multiply 4.5 by 30.48. The answer is 137 cm.

Your turn...

a. Convert 175 yards to meters. (You might need more than one fraction!)

b. Convert 2.50 inches to millimeters. (More than one fraction is needed!)

STUDY SKILLS

Handy Conversion Factors

Copy these handy conversion factors down so you can use them anytime you need to set up a unit canceling problem like the one on this page. *Note*: You can flip these fractions around as needed; the "1" (larger unit) isn't always in the denominator.

Solve first Look later

a. 160 m

b. 63.5 mm

Section 1.3 Review

1. What does it mean to “convert” from one unit to another? Give an example.
2. What are the general mathematical operations you use when converting from one SI unit to another?
3. How many meters do you cover in a 10 km (10-K) race?
4. An Olympic swimming pool is 50 meters long. You swim from one end to the other four times.
   a. How many meters do you swim?
   b. How many kilometers do you swim?
   c. How many centimeters do you swim?
5. In the United States, a standard letter-sized piece of paper is 8.5 inches wide by 11 inches long. The international standard for a letter-sized piece of paper is different. The international standard is based on SI units: 21.0 cm wide by 29.7 cm long.
   a. Convert 21.0 cm to inches. Show your dimensional analysis setup.
   b. Convert 29.7 cm to inches. Show your dimensional analysis setup.
   c. State the dimensions, in inches, of the international standard for a letter-sized piece of paper.
   d. Which piece of paper is longer: a U.S. letter-sized piece of paper, or an international letter-sized piece of paper?
   e. Suppose the United States adopted the international standard for letter-sized paper. Explain at least two things that might result from this change.
6. The height of an average adult person is closest to:
   a. 1.0 meter
   b. 1.8 meters
   c. 5.6 meters

JOURNAL

Find Out!

What are the official measurements for an Olympic swimming pool? Create a table in your journal with the answers:

- length of pool
- width of pool
- number of lanes
- lane width
- water temperature
- depth

KEYWORDS

Do an Internet search using the keywords “international paper size.” Write a report of your findings about the standards for paper sizes. Do all countries use the same size paper for letters? How was the international standard paper size defined? What are some interesting outcomes of having different standard paper sizes in different countries? What surprised you the most about your research?

1.4 Working with Measurements

All measurements involve a degree of uncertainty. The object in Figure 1.9 is definitely longer than 2.6 centimeters. But how much longer? Not everyone would agree on the third digit of the measurement. Is it 2.63 cm or 2.65 cm? In this section, you will explore different ways to work with measured quantities where every measurement involves some amount of error or uncertainty. How much is acceptable? Read on to find out.

VOCABULARY

significant digits - meaningful digits in a measured quantity.

Significant digits

Uncertainty in measurements

In the real world it is *impossible* to make a measurement of the exact true value of anything (except when counting). Using a meter stick the paper clip is 2.65 cm. To a scientist this number means “between 2.62 and 2.67 cm.” The last digit, 5, representing the smallest amount, is always considered to be rounded up or down. **Significant digits** are the meaningful digits in a measured quantity. For the paper clip, the third digit serves to tell someone that the object is about halfway between 2.6 and 2.7 cm long. Therefore, we say there are three useful or significant digits in the length measurement. It is important to be honest when reporting a measurement, so readers know how much resolution it has. We do this by using significant digits.

Using significant digits in math problems

What happens when you use measured quantities with different numbers of significant digits in a math problem? A shoe is 38 cm long and you want to convert the length to inches:

$$38 \text{ cm} \times \left(\frac{1 \text{ inch}}{2.54 \text{ cm}}\right) = ?$$

To find the answer, divide 38 by 2.54 and you get 14.960629. This answer has an artificially large number of significant digits (eight). An answer involving measured quantities should have no more resolution than the starting measurement with the least number of significant digits. The correct answer to this conversion problem is rounded up to 15 inches, since 38 centimeters has two significant digits. Study the next page for more help with using significant digits in math problems.

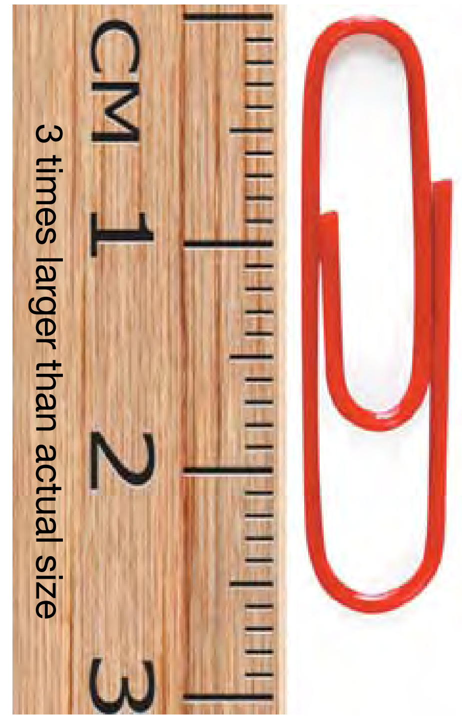


Figure 1.9: *Find the length of the object in centimeters. How many digits does your answer have?*

MA.912.S.1.2-Determine appropriate and consistent standards of measurement for the data to be collected in a survey or experiment.

Solving Problems: Significant Digits

What is the area of an 8.5 inch by 11.0 inch piece of paper?

1. Looking for: You are asked for an area.

2. Given: You are given the width, 8.5 inches, and the height, 11.0 inches.

3. Relationships: Area = width × length

4. Solution: Area = 8.5 inch × 11.0 inch

Area = 93.5 square inches

93.5 has three significant digits. The width measurement had only two significant digits, and the length measurement had three significant digits. So how many significant digits should your answer have? That's right, the answer can have no more significant digits than the measurement with the least number. In this case, since the width measurement only had two significant digits, your answer can only have two. You must round 93.5 square inches to 94 square inches. The correct answer is 94 square inches.

Your turn...

a. How many significant digits does each of these numbers have?
40 cm, 4 cm, 4.0 cm, 40. cm, 45 cm, 450 cm, 450. cm

b. Convert 1.10 miles to kilometers and report your answer with the correct number of significant digits. Use the relationship 1 mi = 1.6 km.

STUDY SKILLS

Which digits are significant?

Digits that are *always significant*:

1. Non-zero digits.
2. Zeros between two significant digits.
3. All *final* zeros to the *right* of a decimal point.

Digits that are *never significant*:

1. Leading zeros to the right of a decimal point. (0.002 cm has only one significant digit.)
2. Final zeros in a number that does not have a decimal point.

Note: A decimal point is used after a whole number ending in zero to indicate that a final zero *is* significant. Thus, 50. cm has two significant digits, not one.

Solve first Look later

a. 40 cm: 1; 4 cm: 1;
4.0 cm: 2; 40. cm: 2;
45 cm: 2; 450 cm: 2;
450. cm: 3

b. 1.8 km

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 1.10). **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 1.10). 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 1 second. Without a second hand, the resolution of a clock would be only 1 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.

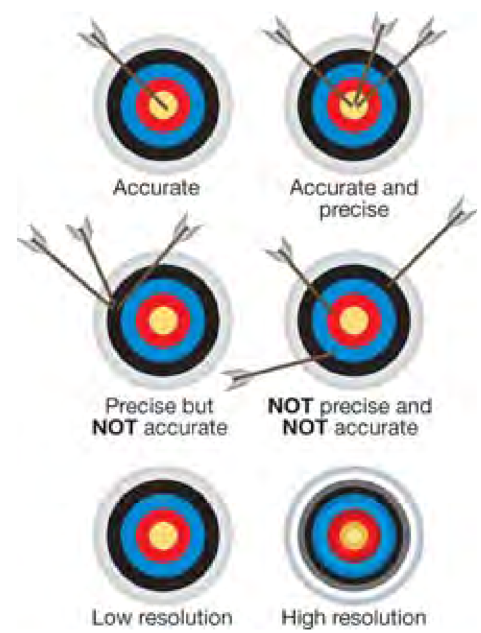


Figure 1.10: *Accuracy, precision, and resolution.*

MA.912.S.1.2-Determine appropriate and consistent standards of measurement for the data to be collected in a survey or experiment.
SC.912.N.4.1-Explain how scientific knowledge and reasoning provide an empirically-based perspective to inform society's decision making.

Comparing measurements

Reproducible measurements Precise measurements are *reproducible*. This means a measurement gives the same result if you or any one else makes the same measurement again in the same way. This brings up a key question: How can you tell if two results are the same when both contain uncertainty (often called *error*)?

Measurements that are the same are not significantly different In everyday conversation, "same" means two numbers that are exactly the same, like 2.56 and 2.56. When comparing scientific results, however, "same" means "*not significantly different.*" **Significant differences** are differences that are much larger than the estimated uncertainty (or error) in the results. That means two results are "the same" *unless* their difference is greater than the estimated error. *This is important to remember.*

Comparing data sets You will collect lots of data when you do the investigations for this physical science course. Once you collect data, you usually compare measurements to check for differences. For example, suppose two different groups of students use electronic timers to measure the time it takes a cart to pass between two points on a ramp. Each group makes four measurements and takes the average (Figure 1.13). Are the results different or are they the same? The numbers 0.3352 and 0.3349 *are* different. But is the difference *significant* or could it just be uncertainty?

Finding estimated error To answer the question, we need to estimate the uncertainty, or error. When we estimate error in a data set, we will *assume the average is the exact value*. Our estimated error will be the average of the differences (use absolute value, drop negative signs) between each measured value and the group average time (see problem solving steps on the next page).

Looking for significant differences Use the estimated error to decide if two results are the same or if they are significantly different. If the difference in the averages is at least three times larger than the estimated error, you can assume the difference is significant. In Figure 1.11, the difference between the groups' time averages is only 0.0003 seconds. This is *not* three times larger than the estimated error of 0.0002 seconds. We conclude that the two experiments produced "the same" result, meaning that the results are not significantly different.

VOCABULARY

significant difference - two results are only significantly different if their difference is much larger than the estimated error.

	Group 1 Time (s)	Est. Error (+/–)	Group 2 Time (s)	Est. Error (+/–)
1	0.3356	0.0004	0.3346	0.0003
2	0.3351	0.0001	0.3353	0.0004
3	0.3349	0.0003	0.3349	0.0000
4	0.3352	0.0000	0.3347	0.0002
AVG	0.3352	0.0002	0.3349	0.0002

Figure 1.11: *The groups have different time averages. Are the averages close enough to be called "the same" result?* Note: *The estimated error is calculated by taking the group average time and subtracting each individual trial time. The estimated error is an absolute value; drop any negative signs.*

SC.912.N.1.3-Recognize that the strength or usefulness of a scientific claim is evaluated through scientific argumentation, which depends on critical and logical thinking, and the active consideration of alternative scientific explanations to explain the data present.
SC.912.N.4.1-Explain how scientific knowledge and reasoning provide an empirically-based perspective to inform society's decision making.

Solving Problems: Comparing Data Sets

Table 1.3: Comparing Data

Trial	Group 1 mass (g)	Est. Error (+/–)	Group 2 mass (g)	Est. Error (+/–)
1	2.6	**0.0**	2.1	**0.0**
2	2.7	**0.1**	2.2	**0.1**
3	2.8	**0.2**	2.1	**0.0**
AVERAGE	**2.7**	**0.1**	**2.1**	**0.03**

Two groups of students were each given their own small container of candy mints. Each group counted out 15 mints and divided them into 3 piles of 5 mints each. Then they found the mass of each collection of 5 mints. Are the average masses significantly different, or are they the same?

1. Looking for: Significant difference between two data sets.

2. Given: Masses in Table 1.3.

3. Relationships:

- estimated trial error = avg mass – trial mass (drop negative signs)
- If difference between averages is *at least three times the largest estimated error average*, then we will conclude that the results are significantly different.

4. Solution: See bold numbers in Table 1.3 for answers.

The difference between the averages: (2.6 – 2.1) = 0.5

The difference of 0.5 is five times greater than the largest estimated error (0.1), so the results are significantly different; the groups probably had different brands of mints!

Your turn...

a. Study the table in Figure 1.12. Are the group averages significantly different? Show your work to prove your answer.

Group 1 time (s)	Group 2 time (s)
0.1776	0.2134
0.1780	0.2130
0.1772	0.2129
0.1777	0.2137

Figure 1.12: *Two groups of students record how long it takes a cart to pass between two points on a ramp. Each group does four time trials. Are their averages significantly different?*

Solve first Look later

Group 1 avg = 0.1776 s

Group 2 avg = 0.2132 s

Difference = 0.0356 s; This is significant. One group had the ramp at a greater angle than the other. Can you tell which one had the higher ramp angle? (Group 1)

SC.912.N.1.1-Define a problem based on a specific body of knowledge, for example: biology, chemistry, physics, and earth/space science.s

Section 1.4 Review

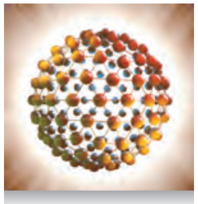
1. Which of these measurements has 3 significant digits? (*There may be more than one correct answer choice.*)
   a. 29.3 cm
   b. 290 cm
   c. 0.029 cm
   d. 290. cm
2. Convert 345 cm to inches. Show your dimensional analysis setup and report your answer with the correct number of significant digits. (1 in = 2.54 cm).
3. Four different students measure the length of a toy cart. The manufacturer reports the length to be 10.5 cm. Study the data in Figure 1.13 and answer the questions below.
   a. Are the measurements accurate? Explain why or why not.
   b. Are the measurements precise? Explain why or why not.
   c. Do the measurements all have the same resolution? Explain.
4. What does it mean when two measured quantities are different but not *significantly* different?
5. All measurements contain some error. Why is this a true statement?
6. Suppose you are going to measure the length of a pencil in centimeters. What should you do to get the most accurate measurement? If you give the ruler to three different friends, what should they do to achieve good precision?
7. Refer to Figure 1.14 to answer these questions:
   a. What is the resolution of the stopwatch?
   b. Time measurements from a stopwatch are not very precise. Why not?

Measurement take by:	Length of toy cart (cm)
Jessica	10
Marco	10.5
Julius	10.8
Steve	11

Figure 1.13: *Question 3.*

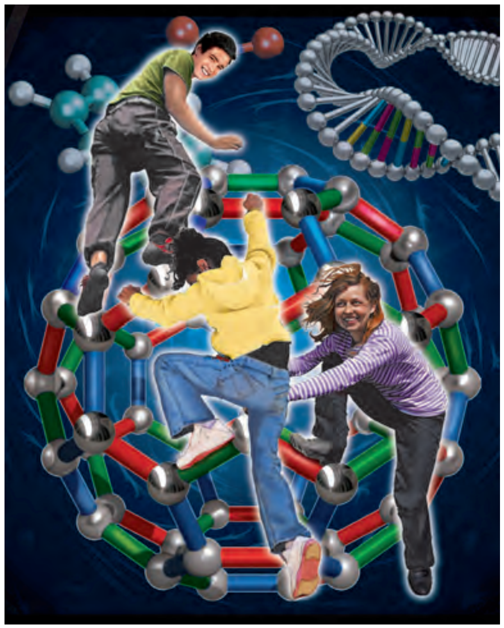
Figure 1.14: *Question 7.*

Nanotechnology



It's a Small World After All

If you could shrink yourself to the size of a molecule, what do you think you would see? You might think you had just been dropped into an enormous climbing structure made from magnetic toys. You'd see atoms arranged in all sorts of amazing geometric patterns—like rings of benzene, tetrahedron-shaped methane molecules, and the intricate DNA double helix.



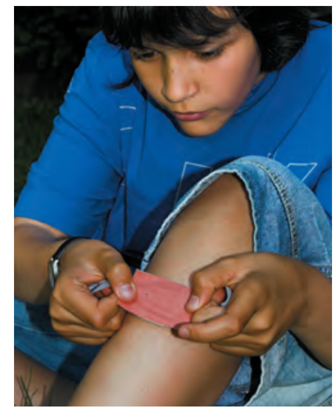
Chemists have known for years that, in nature, atoms are arranged in many different geometric patterns, and that each of these patterns forms a substance with its own unique properties.

Nanotechnology is the exciting new branch of science that attempts to arrange individual atoms into specific patterns, forming molecules that can do incredible things. Someday, these molecules may be able to repair damaged cells in the body, fight diseases, form tiny circuits, and create super-strong, extremely lightweight materials.

Nanotechnology is based on a unit of measurement called a nanometer, which is one billionth of a meter. Comparing a nanometer with a meter is like comparing a marble with the planet Earth. What registers on the nanometer scale? A double-helix DNA molecule has a width of two nanometers. Bacteria have a width of about 200 nanometers. A sheet of paper has a thickness of 100,000 nanometers.

By manipulating the nanoworld, scientists can influence the visible world. This is because an object's observable properties, such as strength and electrical conductivity, begin on the nano or molecular level.

Nanotech: More Common Than You Think



Nanotechnology is currently used to make many everyday products. Small hair-like molecules, or nanoparticles, of zinc oxide are currently used as a water and stain repellent on clothing. These nanoparticles have the ability to pass liquid molecules along from one to the next so water or other liquids cannot seep into the cloth. Nanoparticles are also used in glass to scatter water into small drops to disperse it across a windshield faster. Silver nanoparticles embedded in antimicrobial bandages break up bacterial cell membranes, bind to bacteria's DNA, and interrupt bacteria metabolism.

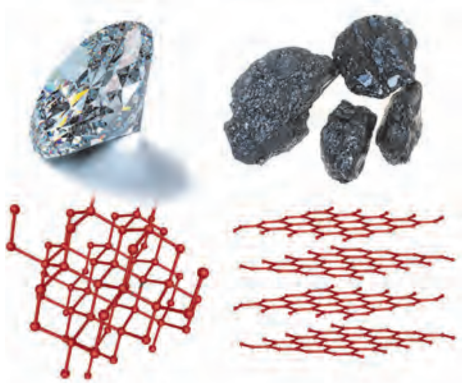
The Wonder Nanoparticle: Carbon Nanotubes

Why is steel stronger than wood? It has to do with the particular molecules and atoms that make up each material and the bonds between those particles. The bonds between steel particles are stronger than those between wood particles.

Now imagine a substance that is hundreds of times stronger than steel but weighs six times less. What you're imagining actually exists. It's carbon made from carbon nanotubes.

SC.912.L.16.10–Evaluate the impact of biotechnology on the individual, society and the environment, including medical and ethical issues.

How carbon atoms are arranged



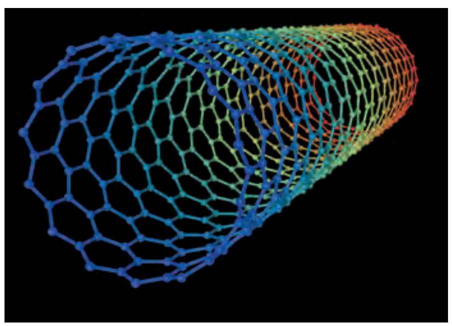
Diamond
Diamond

Carbon
Graphite

Carbon has two well known forms, or allotropes: diamond and graphite. As you know, diamond is much stronger than graphite; this is due to the arrangement and stronger bonds between the carbon atoms in a diamond allotrope's structure.

The carbon nanotube is a third kind of carbon, with capabilities far beyond the materials we use today. This allotrope is composed of cylinders of carbon atoms a few nanometers in width but thousands in length. Their special structure allows carbon nanotubes (CNTs) to have unique properties. They are excellent conductors of electricity and heat because they can conduct with little resistance, behaving as tiny electrical wires or thermal energy "pipelines." They also allow the carbon material to be very, very strong and lightweight.

Carbon nanotubes are still in development because of the difficulty in processing them for mass production. However NASA and many companies are researching their use with polymers and epoxies for construction of spacecraft, aircraft, cars, and skyscrapers. CNTs are more commonly used in electrical circuit applications because smaller amounts of them are needed and because of their outstanding electrical properties.



The carbon nanotube allotrope is usually manufactured in laboratories under high heat, high pressure, and controlled conditions.

Nanomedicine: The New Frontier

Did you ever wonder how medicines work in the body? A medicine's effectiveness depends in part on its bioavailability, or how well the medicine can travel through the blood to the part of the body where it is needed. Due to their size, nanoparticles incorporated into a drug can pass easily through cell membranes, making bioavailability more efficient. The size of nanoparticles is also important for fighting disease because many diseases affect processes within the cell itself, such as the production of proteins that govern immune responses. Diseases like rheumatoid arthritis and multiple sclerosis elevate the production of these proteins, activating the immune responses of the body unnecessarily. Diseases like these can only be impeded by drugs that have the ability to penetrate a cell membrane.

One current application of nanotechnology is in the surgical removal of certain types of tumors. Surgeons can inject cadmium selenide nanoparticles into a tumor to locate its boundaries. When exposed to UV light, these nanoparticles glow and effectively illuminate the tumor so the surgeon can remove it more precisely.

What if biological nanomachines could seek out a broken part of a cell and fix it? What if a bio nanomachine could seek out cancer cells and destroy them? How can a nanomachine mimic nature's ability to heal? These are the cutting-edge questions that nanomedicine scientists are trying to answer. Their research includes the development of molecular machines that have the ability to mimic nature's healing processes by entering cells, sensing dysfunction, and making appropriate modifications by either repairing damaged cells or manufacturing new ones. Scientists predict these cell-repair machines will have the ability to open and close cell membranes and correct a single molecular disorder like DNA damage.

Questions:

1. A nanometer is what fraction of a meter?
2. Name two practical applications of nanotechnology.
3. Research: Use the Internet keyword search: NASA + "carbon nanotubes" to learn how NASA plans to use this technology. Briefly explain three possible applications.

SC.912.L.16.10–Evaluate the impact of biotechnology on the individual, society and the environment, including medical and ethical issues.

Chapter 1 Assessment

Vocabulary

Select the correct term to complete the sentences.

accuracy	length	resolution
conversion factor	mass	SI
dimensional analysis	measurement	significant difference
distance	meter	significant digits
English System	precision	unit

Section 1.1

1. A _____ is a standard amount, like a kilometer or a gallon, which is used to communicate different quantities.
2. The ____ is a measurement system used for everyday measurements in the United States.
3. ____ is the international system of units used by scientists worldwide.
4. When someone determines the amount of something using a value and a unit, they are making a(n) ____.
5. The amount of matter an object contains is its ____.

Section 1.2

6. ____ describes how far it is from one place to any other place.
7. The amount of space between two points is measured in units of ____.
8. A(n) ____ is a unit of length in SI that equals 100 centimeters.

Section 1.3

9. A ratio that has a value of one and is used when setting up unit conversion problems is called a(n) ____.
10. A method of using conversion factors and unit canceling to solve a unit conversion problem is called ____.

Section 1.4

11. Meaningful digits in a measured quantity are known as ____.
12. ____ refers to the smallest interval that can be measured.
13. When you describe how close a measured quantity is to a true or accepted value, you are describing its ____.
14. ____ describes how close together repeated measurements are.
15. If the difference between two results is larger than the estimated error, the result is called a(n) ____.

Concepts

Section 1.1

1. Explain, using examples, how SI and English systems of measurement are both used in daily life in the United States.
2. All SI units use a common set of prefixes. For example, you can have milligrams, milliliters, and millimeters. What does *milli* mean in each case? How are these units similar? How are they different?

Section 1.2

3. What are the two different ways to understand time? Give examples to support your explanation.
4. In the following list of units, which are SI units of length? mm, yd, cm, mi, m, g, mg, lb, oz, km, ml

5. What unit is represented by the smallest intervals printed on a centimeter ruler?

Section 1.3

6. How do you use the SI conversion tool to perform metric conversions? Explain, step-by-step, using your own example.
7. Why can't you use the SI conversion tool to convert from SI to English units?
8. The dimensional analysis method of unit conversion is sometimes called "unit canceling." Explain why this is a good name for the method.

Section 1.4

9. Suppose you are measuring the height of a small child. What will determine the number of significant digits you record?
10. Why do you often have to round off answers to math problems that involve measured quantities?
11. Compare and contrast the terms *accuracy*, *precision*, and *resolution*. What do they have in common? How are they different?
12. How can two experimental results be considered "the same" if the numbers are not exactly the same?

Problems

Section 1.1

1. Which of the following is closest to 2 cm?
   a. the width of your pinky finger
   b. the length of a dollar bill
   c. the length of a small paperclip
2. Rank these units from smallest to largest: micrometer, nanometer, kilometer, centimeter, meter.

Section 1.2

3. Arrange the following intervals of time from shortest to longest: 160 seconds, 2 minutes, 2 minutes 50 seconds.
4. Write 3,800 seconds in hours, minutes, and seconds.
5. Report the length of the object shown below.

6. How many millimeters is represented by 6.7 cm?

Section 1.3

7. Convert 54 grams to kilograms.
8. Convert 26 decimeters to meters.
9. Convert 1,200 meters to millimeters.
10. Convert 525 pounds to kilograms. Show your dimensional analysis setup. 1 kilogram = 2.2 pounds.
11. A runner completes a 4,000.-meter race. How many yards did she run? Show your dimensional analysis setup.

Section 1.4

12. A meter stick with millimeters as its smallest graduation is used to measure a wood block. Which value correctly represents the resolution of the best measurement that can be made?
    a. 20 cm
    b. 20.5 cm
    c. 205.5 mm
    d. 205.53 mm

Wind-up Toy Travel Times

Group 1	Group 2
Time (s)	Time (s)
2.56	1.23
2.62	1.29
2.75	1.22
2.65	1.24

13. Two groups of students test the same wind-up toy. Each group conducts four trials to find out how long it takes the toy to travel 1 meter. Study their data in the table above and answer the questions.
    a. Find the average time for each group's four trials.
    b. Estimate the average error for each group.
    c. Which group had the best precision? Explain.
    d. What was the resolution of the stopwatch?
    e. The group averages are quite different. Are they significantly different? Explain, and use a very simple math problem to prove your answer.
    f. One of the groups actually had the wind-up toy travel down a ramp for 1 meter, and the other group had their toy travel across a flat surface. Which group was which? Explain how you know.

Applying Your Knowledge

Section 1.1

1. Do some research to find out what influenced the development of the International System of Units. Where did the system originate? When did other countries decide to adopt the system? Did the United States adopt the system? (You may be surprised at what your research will reveal!)
2. Do you think the United States will ever switch completely to SI? Why or why not?

Section 1.2

3. What is the distance from Earth to the Moon? Is that distance changing? Do some research to find out.

Section 1.3

4. Why do you think it is necessary to know how to convert from English to SI units and vice versa? Give your own example.

Section 1.4

5. Measuring time is necessary for many Olympic events. Choose one Olympic event and write a report on how time is measured, and how much resolution is necessary.
6. You are asked to find the area of a room that measures 24.5 meters by 21 meters. How many significant digits should the answer have?

LA.910.2.2.3-The student will organize information to show understanding or relationships among facts, ideas, and events.