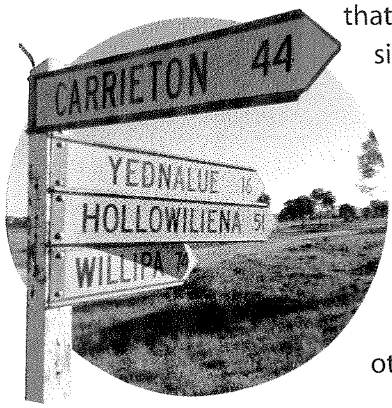
3.2 The International System of Units

Connecting to Your World

"Are we there yet?" You may have asked this question during a long road trip with family or friends. To find out how much farther you have to go, you can read the roadside signs that list destinations and their distances. In the signs shown here, however, the distances are listed as numbers with no units attached. Is Carrieton 44 kilometers or 44 miles away? Without the units, you can't be sure. When you make a measurement, you must assign the correct units to the numerical value. Without the units, it is impossible to communicate the measurement clearly to others.



Guide for Reading

Key Concepts

- Which five SI base units do chemists commonly use?
- What metric units are commonly used to measure length, volume, mass, temperature, and energy?

Vocabulary

International System of Units (SI)
meter (m)
liter (L)
kilogram (kg)
gram (g)
weight
temperature
Celsius scale
Kelvin scale
absolute zero
energy
joule (J)
calorie (cal)

Reading Strategy

Summarizing As you read about SI units, summarize the main ideas in the text that follows the red and blue headings.

Measuring with SI Units

All measurements depend on units that serve as reference standards. The standards of measurement used in science are those of the metric system. The metric system is important because of its simplicity and ease of use. All metric units are based on multiples of 10. As a result, you can convert between units easily. The metric system was originally established in France in 1795. The **International System of Units** (abbreviated **SI,** after the French name, *Le Système International d'Unités*) is a revised version of the metric system. The SI was adopted by international agreement in 1960. There are seven SI base units, which are listed in Table 3.1. From these base units, all other SI units of measurement can be derived. **The five SI base units commonly used by chemists are the meter, the kilogram, the kelvin, the second, and the mole.**

All measured quantities can be reported in SI units. Sometimes, however, non-SI units are preferred for convenience or for practical reasons. In this textbook you will learn about both SI and non-SI units.

Table 3.1

SI Base Units

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

Table 3.2

Commonly Used Metric Prefixes

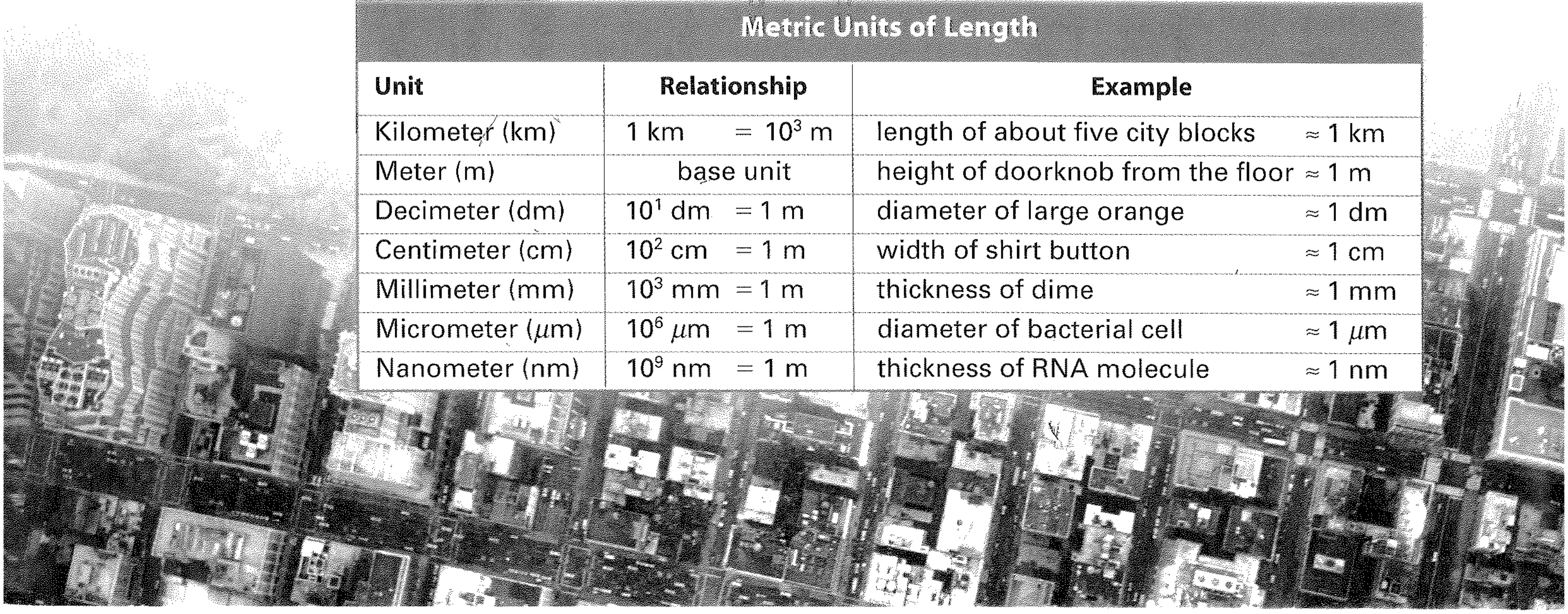
Prefix	Meaning	Factor
mega (M)	1 million times larger than the unit it precedes	10^6
kilo (k)	1000 times larger than the unit it precedes	10^3
deci (d)	10 times smaller than the unit it precedes	10^{-1}
centi (c)	100 times smaller than the unit it precedes	10^{-2}
milli (m)	1000 times smaller than the unit it precedes	10^{-3}
micro (μ)	1 million times smaller than the unit it precedes	10^{-6}
nano (n)	1000 million times smaller than the unit it precedes	10^{-9}
pico (p)	1 trillion times smaller than the unit it precedes	10^{-12}

Units and Quantities

As you already know, you don't measure length in kilograms or mass in centimeters. Different quantities require different units. Before you make a measurement, you must be familiar with the units corresponding to the quantity that you are trying to measure.

Units of Length Size is an important property of matter. In SI, the basic unit of length, or linear measure, is the **meter (m)**. All measurements of length can be expressed in meters. (The length of a page in this book is about one-fourth of a meter.) For very large and very small lengths, however, it may be more convenient to use a unit of length that has a prefix. Table 3.2 lists the prefixes in common use. For example, the prefix *milli-* means 1/1000 (one-thousandth), so a millimeter (mm) is 1/1000 of a meter, or 0.001 m. A hyphen (-) measures about 1 mm.

For large distances, it is usually most appropriate to express measurements in kilometers (km). The prefix *kilo-* means 1000, so 1 km equals 1000 m. A standard marathon distance race of about 42,000 m is more conveniently expressed as 42 km (42×1000 m). **Common metric units of length include the centimeter, meter, and kilometer.** Table 3.3 summarizes the relationships among metric units of length.

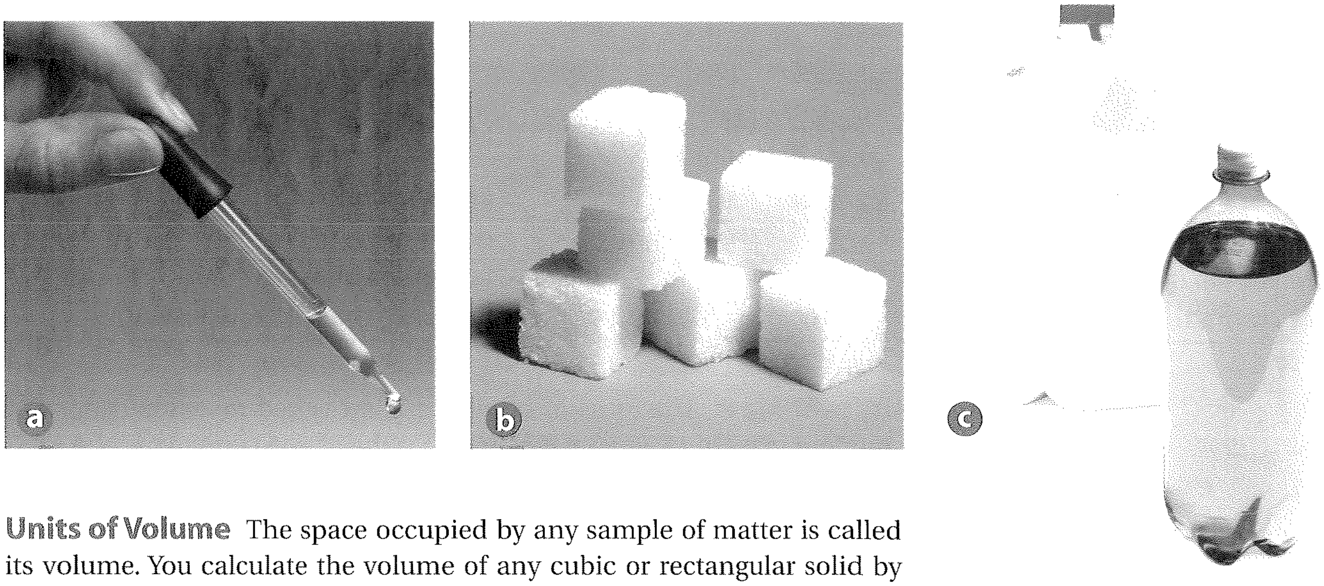


Length of 5 city blocks ≈ 1 km

Table 3.3

Metric Units of Length

Unit	Relationship	Example
Kilometer (km)	1 km = 10^3 m	length of about five city blocks ≈ 1 km
Meter (m)	base unit	height of doorknob from the floor ≈ 1 m
Decimeter (dm)	10^1 dm = 1 m	diameter of large orange ≈ 1 dm
Centimeter (cm)	10^2 cm = 1 m	width of shirt button ≈ 1 cm
Millimeter (mm)	10^3 mm = 1 m	thickness of dime ≈ 1 mm
Micrometer (μm)	10^6 μm = 1 m	diameter of bacterial cell ≈ 1 μm
Nanometer (nm)	10^9 nm = 1 m	thickness of RNA molecule ≈ 1 nm



Units of Volume The space occupied by any sample of matter is called its volume. You calculate the volume of any cubic or rectangular solid by multiplying its length by its width by its height. The unit for volume is thus derived from units of length. The SI unit of volume is the amount of space occupied by a cube that is 1 m along each edge. This volume is a cubic meter (m^3). An automatic dishwasher has a volume of about 1 m^3.

A more convenient unit of volume for everyday use is the liter, a non-SI unit. A **liter (L)** is the volume of a cube that is 10 centimeters (10 cm) along each edge (10 cm × 10 cm × 10 cm = 1000 cm^3 = 1 L). A decimeter (dm) is equal to 10 cm, so 1 L is also equal to 1 cubic decimeter (dm^3). A smaller non-SI unit of volume is the milliliter (mL); 1 mL is 1/1000 of a liter. Thus there are 1000 mL in 1 L. Because 1 L is defined as 1000 cm^3, 1 mL and 1 cm^3 are the same volume. The units milliliter and cubic centimeter are thus used interchangeably. **Common metric units of volume include the liter, milliliter, cubic centimeter, and microliter.** Table 3.4 summarizes the relationships among these units of volume.

There are many devices for measuring liquid volumes, including graduated cylinders, pipets, burets, volumetric flasks, and syringes. Note that the volume of any solid, liquid, or gas will change with temperature (although the change is much more dramatic for gases). Consequently, accurate volume-measuring devices are calibrated at a given temperature—usually 20 degrees Celsius (20°C), which is about normal room temperature.

Checkpoint ***What is the SI unit of volume?***

Figure 3.6 These photographs above give you some idea of the relative sizes of some different units of volume. (a) The volume of 20 drops of liquid from a medicine dropper is approximately 1 mL. (b) A sugar cube is 1 cm on each edge and has a volume of 1 cm^3. Note that 1 mL is the same as 1 cm^3. (c) A gallon of milk has about twice the volume of a 2-L bottle of soda.
Calculating ***How many cubic centimeters are in 2 liters?***

Table 3.4

Metric Units of Volume

Unit	Relationship	Example
Liter (L)	base unit	quart of milk ≈ 1 L
Milliliter (mL)	10^3 mL = 1 L	20 drops of water ≈ 1 mL
Cubic centimeter (cm^3)	1 cm^3 = 1 mL	cube of sugar ≈ 1 cm^3
Microliter (μL)	10^6 μL = 1 L	crystal of table salt ≈ 1 μL

Table 3.5

Metric Units of Mass		
Unit	**Relationship**	**Example**
Kilogram (kg) (base unit)	1 kg = 10^3 g	small textbook ≈ 1 kg
Gram (g)	1 g = 10^{-3} kg	dollar bill ≈ 1 g
Milligram (mg)	10^3 mg = 1 g	ten grains of salt ≈ 1 mg
Microgram (μg)	10^6 μg = 1 g	particle of baking powder ≈ 1 μg

Units of Mass The mass of an object is measured in comparison to a standard mass of 1 **kilogram (kg),** which is the basic SI unit of mass. A kilogram was originally defined as the mass of 1 L of liquid water at 4°C. A cube of water at 4°C measuring 10 cm on each edge would have a volume of 1 L and a mass of 1000 grams (g), or 1 kg. A **gram (g)** is 1/1000 of a kilogram; the mass of 1 cm^3 of water at 4°C is 1 g. **Common metric units of mass include the kilogram, gram, milligram, and microgram.** The relationships among units of mass are shown in Table 3.5.

You can use a platform balance to measure the mass of an object. The object is placed on one side of the balance, and standard masses are added to the other side until the balance beam is level. The unknown mass is equal to the sum of the standard masses. Laboratory balances range from very sensitive instruments with a maximum capacity of only a few milligrams to devices for measuring quantities in kilograms. An analytical balance is used to measure objects of less than 100 g and can determine mass to the nearest 0.0001 g (0.1 mg).

The astronaut shown on the surface of the moon in Figure 3.7 weighs one sixth of what he weighs on Earth. The reason for this difference is that the force of gravity on Earth is about six times what it is on the moon. **Weight** is a force that measures the pull on a given mass by gravity. Weight, a measure of force, is different from mass, which is a measure of the quantity of matter. Although the weight of an object can change with its location, its mass remains constant regardless of its location. Objects can thus become weightless, but they can never become massless.

Checkpoint ***How does weight differ from mass?***

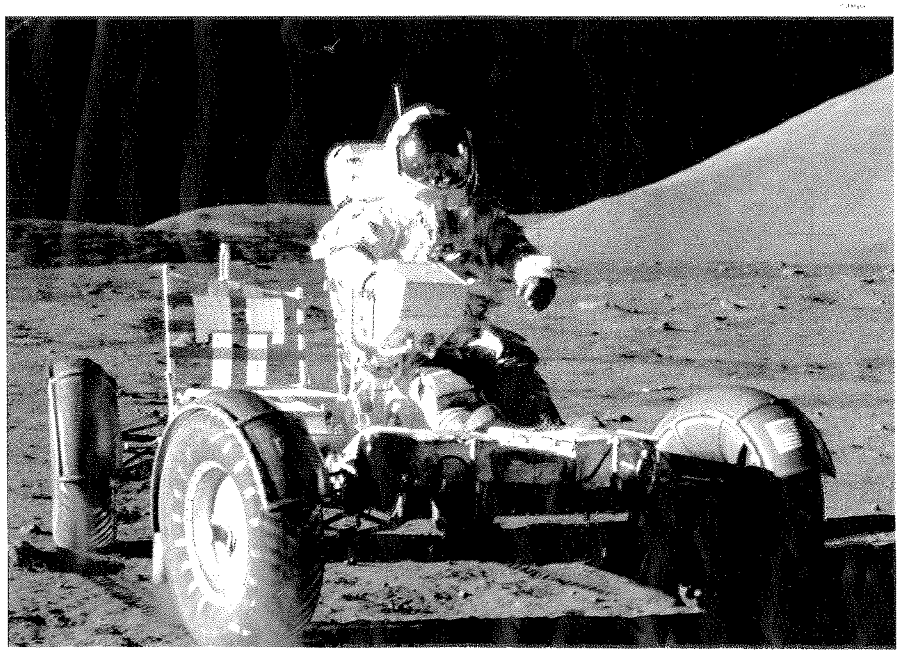
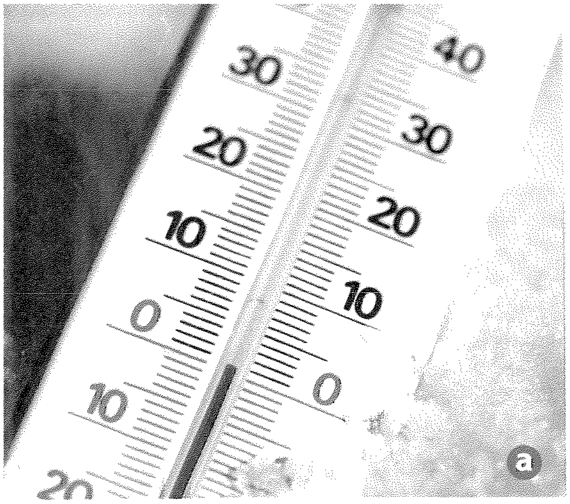


Figure 3.7 An astronaut's weight on the moon is one sixth as much as it is on Earth. Earth exerts six times the force of gravity as the moon. **Inferring** ***How does the astronaut's mass on the moon compare to his mass on Earth?***



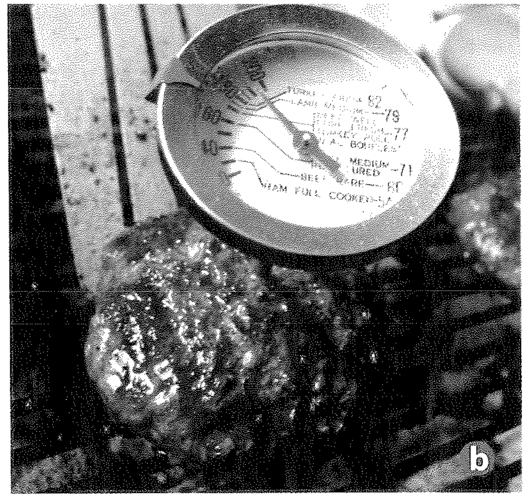


Figure 3.8 Thermometers are used to measure temperature. ⓐ A liquid-in-glass thermometer contains alcohol or mineral spirits. ⓑ A dial thermometer contains a coiled bimetallic strip. ⓒ A Galileo thermometer contains several glass bulbs that are calibrated to sink or float depending on the temperature. The Galileo thermometer shown uses the Fahrenheit scale, which sets the freezing point of water at 32°F and the boiling point of water at 212°F.

Units of Temperature When you hold a glass of hot water, the glass feels hot because heat transfers from the glass to your hand. When you hold an ice cube, it feels cold because heat transfers from your hand to the ice cube. **Temperature** is a measure of how hot or cold an object is. An object's temperature determines the direction of heat transfer. When two objects at different temperatures are in contact, heat moves from the object at the higher temperature to the object at the lower temperature.

Almost all substances expand with an increase in temperature and contract as the temperature decreases. (A very important exception is water.) These properties are the basis for the common liquid-in-glass thermometer. The liquid in the thermometer expands and contracts more than the volume of the glass, producing changes in the column height of liquid. Figure 3.8 shows a few different types of thermometers.

Several temperature scales with different units have been devised. **Scientists commonly use two equivalent units of temperature, the degree Celsius and the kelvin.** The Celsius scale of the metric system is named after the Swedish astronomer Anders Celsius (1701–1744). It uses two readily determined temperatures as reference temperature values: the freezing point and the boiling point of water. The **Celsius scale** sets the freezing point of water at 0°C and the boiling point of water at 100°C. The distance between these two fixed points is divided into 100 equal intervals, or degrees Celsius (°C).

Another temperature scale used in the physical sciences is the Kelvin, or absolute, scale. This scale is named for Lord Kelvin (1824–1907), a Scottish physicist and mathematician. On the **Kelvin scale,** the freezing point of water is 273.15 kelvins (K), and the boiling point is 373.15 K. Notice that with the Kelvin scale, the degree sign is not used. Figure 3.9 on the next page compares the Celsius and Kelvin scales. A change of one degree on the Celsius scale is equivalent to one kelvin on the Kelvin scale. The zero point on the Kelvin scale, 0 K, or **absolute zero,** is equal to −273.15°C. For problems in this text, you can round −273.15°C to −273°C. Because one degree on the Celsius scale is equivalent to one kelvin on the Kelvin scale, converting from one temperature to another is easy. You simply add or subtract 273, as shown in the following equations.

$$K = °C + 273$$

$$°C = K - 273$$

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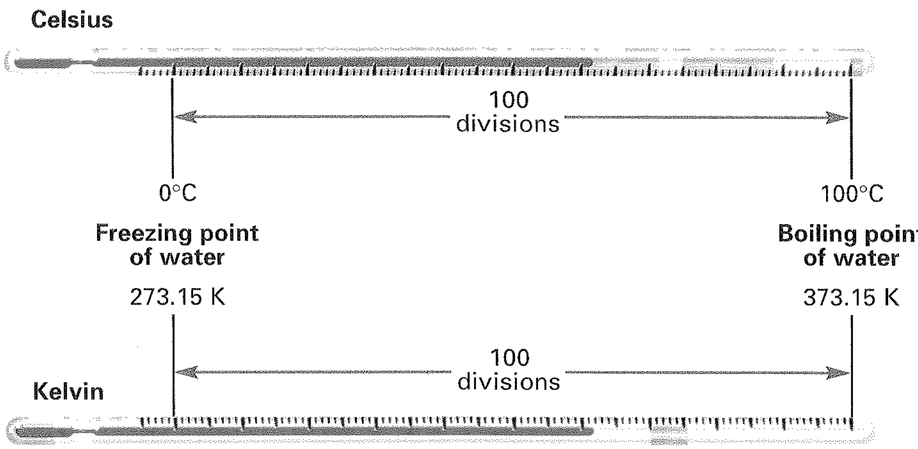
Figure 3.9 These thermometers show a comparison of the Celsius and Kelvin temperature scales. Note that a 1°C change on the Celsius scale is equal to a 1 K change on the Kelvin scale. **Interpreting Diagrams** ***What is a change of 10 K equivalent to on the Celsius scale?***



SAMPLE PROBLEM 3.4

Converting Between Temperature Scales

Normal human body temperature is 37°C. What is that temperature in kelvins?

1 Analyze ***List the known and the unknown.***

Known
- Temperature in °C = 37°C

Unknown
- Temperature in K = ? K

Use the known value and the equation K = °C + 273 to calculate the temperature in kelvins.

2 Calculate ***Solve for the unknown.***

Substitute the known value for the Celsius temperature into the equation and solve.

$$K = °C + 273$$
$$= 37 + 273 = 310\ K$$

3 Evaluate ***Does the result make sense?***

You should expect a temperature in this range, since the freezing point of water is 273 K and the boiling point of water is 373 K; normal body temperature is between these two values.

Math Handbook

For help with algebraic equations, go to page R69.

Practice Problems

16. Liquid nitrogen boils at 77.2 K. What is this temperature in degrees Celsius?

17. The element silver melts at 960.8°C and boils at 2212°C. Express these temperatures in kelvins.

Interactive Textbook

Problem-Solving 3.17
Solve Problem 17 with the help of an interactive guided tutorial.

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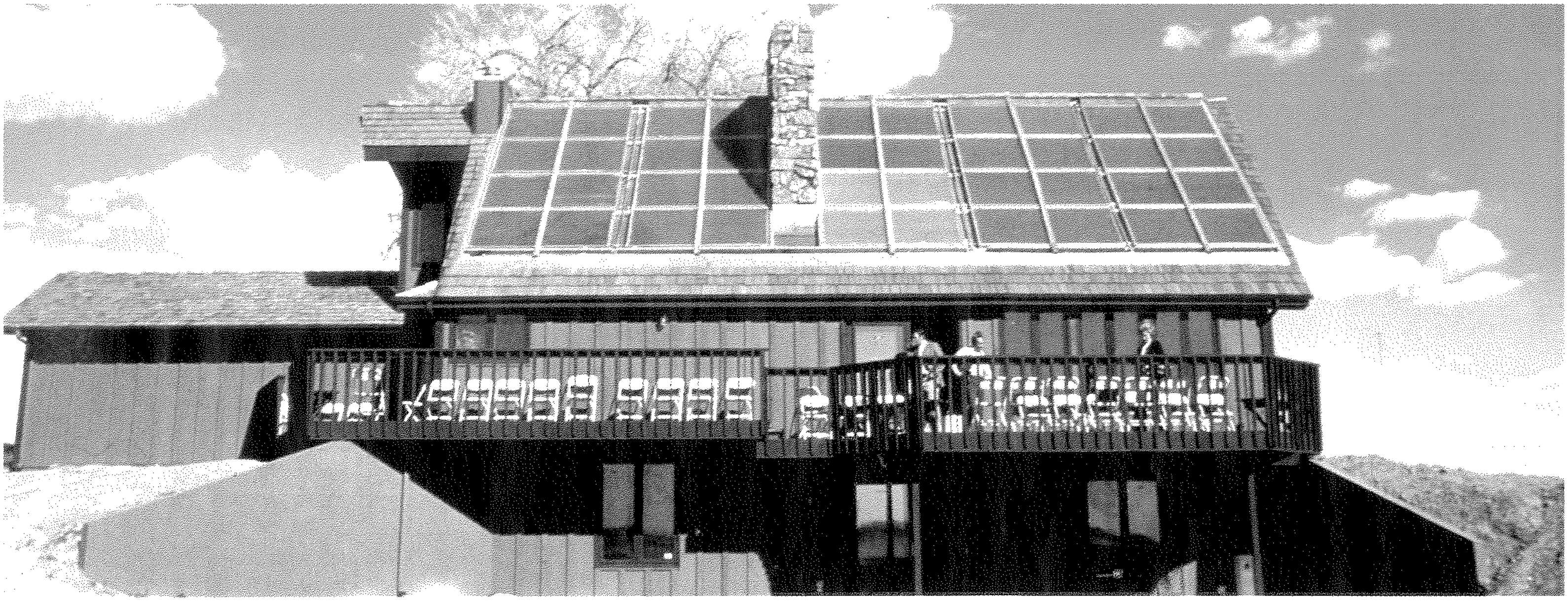

Figure 3.10 Photoelectric panels convert solar energy into electricity.

Units of Energy Figure 3.10 shows a house equipped with solar panels. The solar panels convert the radiant energy from the sun into electrical energy that can be used to heat water and power appliances. **Energy** is the capacity to do work or to produce heat.

Like any other quantity, energy can be measured. **The joule and the calorie are common units of energy.** The **joule (J)** is the SI unit of energy. It is named after the English physicist James Prescott Joule (1818–1889). One **calorie (cal)** is the quantity of heat that raises the temperature of 1 g of pure water by 1°C. Conversions between joules and calories can be carried out using the following relationships.

$$1\ \text{J} = 0.2390\ \text{cal} \qquad 1\ \text{cal} = 4.184\ \text{J}$$

3.2 Section Assessment

18. **Key Concept** Which five SI base units are commonly used in chemistry?
19. **Key Concept** Which metric units are commonly used to measure length, volume, mass, temperature, and energy?
20. Name the quantity measured by each of the seven SI base units and give the SI symbol of the unit.
21. What is the symbol and meaning of each prefix?
    - a. *milli-*
    - b. *nano-*
    - c. *deci-*
    - d. *centi-*
22. List the following units in order from largest to smallest: m^3, mL, cL, μL, L, dL.
23. What is the volume of a paperback book 21 cm tall, 12 cm wide, and 3.5 cm thick?
24. State the difference between mass and weight.
25. State the relationship between degrees Celsius and kelvins.
26. Surgical instruments may be sterilized by heating at 170°C for 1.5 hr. Convert 170°C to kelvins.
27. State the relationship between joules and calories.

Elements Handbook

Boiling Points Look up the boiling points of the first four elements in Group 7A on page R32. Convert these temperatures into kelvins.

Interactive Textbook

Assessment 3.2 Test yourself on the concepts in Section 3.2.

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