Pearson

E.2: The Units of Measurement

The two most common unit systems are the **metric system**, used in most of the world, and the **English system**, used in the United States. Scientists use the **International System of Units (SI)**, which is based on the metric system.

> The abbreviation *SI* comes from the French, *Système International d'Unités.*

The Standard Units

Table E.1 shows the standard SI base units. For now, we focus on the first four of these units: the *meter*, the standard unit of length; the *kilogram*, the standard unit of mass; the *second*, the standard unit of time; and the *kelvin*, the standard unit of temperature.

Table E.1 SI Base Units

Quantity	Unit	Symbol
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

The Meter: A Measure of Length

A **meter (m)** is slightly longer than a yard (1 yard is 36 inches while 1 meter is 39.37 inches). Thus, a 100-yard football field measures only 91.4 meters. The meter was originally defined as 1/10,000,000 of the distance from the equator to the North Pole (through Paris). The International Bureau of Weights and Measures now defines it more precisely as the distance light travels through a vacuum in a designated period of time, 1/299,792,458 second. Scientists commonly deal with a wide range of lengths and distances. The separation between the sun and the closest star (Proxima Centauri) is about 3.8×10^{16} m, while many chemical bonds measure about 1.5×10^{-10} m.

> The velocity of light in a vacuum is 3.00×10^{8} m/s.

> Scientific notation is reviewed in Appendix IA.

The Kilogram: A Measure of Mass

The **kilogram (kg)**, defined as the mass of a metal cylinder kept at the International Bureau of Weights and Measures at Sèvres, France, is a measure of *mass*, a quantity different from *weight*. The **mass** of an object is a measure of the quantity of matter within it, while the weight of an object is a measure of the *gravitational pull* on its matter. If you could weigh yourself on the moon, for example, its weaker gravity would pull on you with less force than does Earth's gravity, resulting in a lower weight. A 130-pound (lb) person on Earth would weigh only 21.5 lb on the moon. However, the person's mass—the quantity of matter in his or her body—remains the same on every planet. One kilogram of mass is the equivalent of 2.205 lb of weight on Earth, so if we express mass in kilograms, a 130-lb person has a mass of approximately 59 kg and this book has a mass of about 2.5 kg. Another common unit of mass is the gram (g). One gram is 1/1000 kg. A nickel (5¢) has a mass of about 5 g.

A nickel (5 cents) weighs about 5 grams.

The Second: A Measure of Time

If you live in the United States, the **second (s)** is perhaps the most familiar SI unit. The International Bureau of Weights and Measures originally defined the second in terms of the day and the year, but a second is now defined more precisely as the duration of 9,192,631,770 periods of the radiation emitted from a certain transition in a cesium-133 atom. (We discuss transitions and the emission of radiation by atoms in Chapter 2.) Scientists measure time on a large range of scales. The human heart beats about once every second; the age of the universe is estimated to be about 4.32×10^{17} s (13.7 billion years); and some molecular bonds break or form in time periods as short as 1×10^{-15} s.

The Kelvin: A Measure of Temperature

The **kelvin (K)** is the SI unit of **temperature**. The temperature of a sample of matter is a measure of the amount of average kinetic energy—the energy due to motion—of the atoms or molecules that compose the matter. The molecules in a *hot* glass of water are, on average, moving faster than the molecules in a *cold* glass of water. Temperature is a measure of this molecular motion.

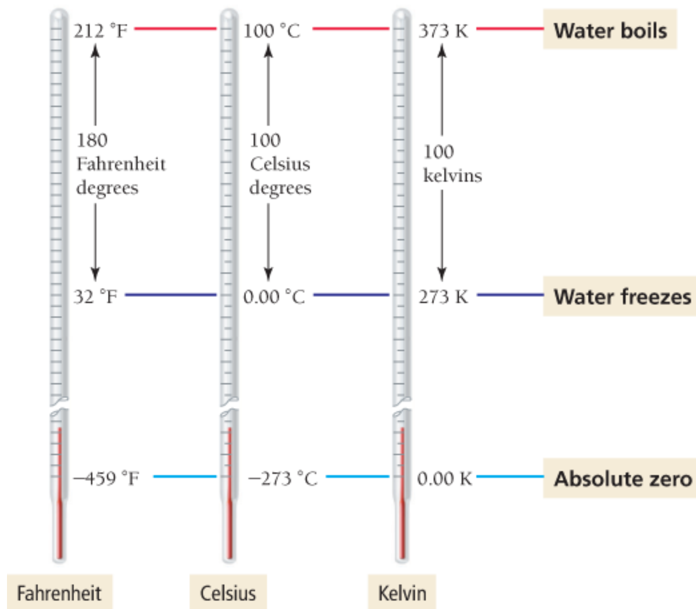
Temperature also determines the direction of thermal energy transfer, or what we commonly call *heat*. Thermal energy transfers from hot objects to cold ones. For example, when you touch another person's warm hand (and yours is cold), thermal energy flows *from that person's hand to yours*, making your hand feel warmer. However, if you touch an ice cube, thermal energy flows *out of your hand* to the ice, cooling your hand (and possibly melting some of the ice cube).

Figure E.2 shows the three temperature scales. The most common in the United States is the **Fahrenheit scale (°F)**. On the Fahrenheit scale, water freezes at 32 °F and boils at 212 °F at sea level. Room temperature is approximately 72 °F. The Fahrenheit scale was originally determined by assigning 0 °F to the freezing point of a concentrated saltwater solution and 96 °F to normal body temperature. Normal body temperature was later measured more accurately to be 98.6 °F.

Figure E.2 Comparison of the Fahrenheit, Celsius, and Kelvin Temperature Scales

The Fahrenheit degree is five-ninths the size of the Celsius degree and the kelvin. The zero point of the Kelvin scale is absolute zero (the lowest possible temperature), whereas the zero point of the Celsius scale is the freezing point of water.

Temperature Scales



Scientists and citizens of most countries other than the United States typically use the **Celsius (°C) scale**, shown in the middle of Figure E.2. On this scale, pure water freezes at 0 °C and boils at 100 °C (at sea level). Room temperature is approximately 22 °C. The Fahrenheit scale and the Celsius scale differ both in the size of their respective degrees and the temperature each designates as "zero." Both the Fahrenheit and Celsius scales allow for negative temperatures.

The SI unit for temperature, as we have seen, is the kelvin, shown on the right in Figure E.2. The **Kelvin scale** (sometimes also called the *absolute scale)* avoids negative temperatures by assigning 0 K to the coldest temperature possible, absolute zero. Absolute zero (−273 °C or −459 °F) is the temperature at which molecular motion virtually stops. Lower temperatures do not exist. The size of the kelvin is identical to that of the Celsius degree—the only difference is the temperature that each designates as zero. You can convert between the temperature scales with these formulas:

$$
\begin{aligned}
{}^{\circ}\mathrm{C} &= \frac{({}^{\circ}\mathrm{F} - 32)}{1.8} \\
\mathrm{K} &= {}^{\circ}\mathrm{C} + 273.15
\end{aligned}
$$

The Celsius Temperature Scale

Note that we refer to Kelvin temperatures in kelvins (*not* "degrees Kelvin") or K (*not* °K).

Example E.1 Converting between Temperature Scales

A sick child has a temperature of 40.00 °C. What is the child's temperature in **(a)** K and **(b)** °F?

SOLUTION

a. Begin by finding the equation that relates the quantity that is given (°C) and the quantity you are trying to find (K).

Since this equation gives the temperature in K directly, substitute in the correct value for the temperature in °C and calculate the answer.

$$\mathrm{K} = {}^{\circ}\mathrm{C} + 273.15$$

$$\mathrm{K} = {}^{\circ}\mathrm{C} + 273.15$$
$$\mathrm{K} = 40.00 + 273.15 = 313.15\ \mathrm{K}$$

b. To convert from °C to °F, find the equation that relates these two quantities.

Since this equation expresses °C in terms of °F, solve the equation for °F.

Now substitute °C into the equation and calculate the answer.

Note: *The number of digits reported in this answer follows significant figure conventions, covered later in this section.*

$${}^{\circ}\mathrm{C} = \frac{({}^{\circ}\mathrm{F} - 32)}{1.8}$$

$$\begin{aligned} {}^{\circ}\mathrm{C} &= \frac{({}^{\circ}\mathrm{F} - 32)}{1.8} \\ 1.8\,({}^{\circ}\mathrm{C}) &= ({}^{\circ}\mathrm{F} - 32) \\ {}^{\circ}\mathrm{F} &= 1.8\,({}^{\circ}\mathrm{C}) + 32 \end{aligned}$$

$${}^{\circ}\mathrm{F} = 1.8\,({}^{\circ}\mathrm{C}) + 32$$
$${}^{\circ}\mathrm{F} = 1.8\,(40.00\ {}^{\circ}\mathrm{C}) + 32 = 104.00\ {}^{\circ}\mathrm{F}$$

FOR PRACTICE E.1

Gallium is a solid metal at room temperature but will melt to a liquid in your hand. The melting point of gallium is 85.6 °F. What is this temperature on (a) the Celsius scale and (b) the Kelvin scale?

Answers to For Practice and For More Practice problems are in Appendix IV.

Prefix Multipliers

Scientific notation (see Appendix IA) allows us to express very large or very small quantities in a compact manner by using exponents. For example, we write the diameter of a hydrogen atom as 1.06×10^{-10} m. The International System of Units uses the **prefix multipliers** shown in Table E.2 with the standard units. These multipliers change the value of the unit by powers of 10 (just like an exponent does in scientific notation). For example, the kilometer has the prefix "kilo" meaning 1000 or 10^3. Therefore,

$$1\ \text{kilometer} = 1000\ \text{meters} = 10^3\ \text{meters}$$

Table E.2 **SI Prefix Multipliers**

Prefix	Symbol	Multiplier	
exa	E	1,000,000,000,000,000,000	(10^{18})
peta	P	1,000,000,000,000,000	(10^{15})
tera	T	1,000,000,000,000	(10^{12})
giga	G	1,000,000,000	(10^{9})

mega	M	1,000,000	(10^6)
kilo	k	1000	(10^3)
deci	d	0.1	(10^{-1})
centi	c	0.01	(10^{-2})
milli	m	0.001	(10^{-3})
micro	μ	0.000001	(10^{-6})
nano	n	0.000000001	(10^{-9})
pico	p	0.000000000001	(10^{-12})
femto	f	0.000000000000001	(10^{-15})
atto	a	0.000000000000000001	(10^{-18})

Similarly, the millimeter has the prefix "milli," meaning 0.001 or 10^{-3}.

$$1 \text{ millimeter} = 0.001 \text{ meters} = 10^{-3} \text{ meters}$$

When we report a measurement, we choose a prefix multiplier close to the size of the quantity we are measuring. For example, to state the diameter of a hydrogen atom, which is 1.06×10^{-10} m, we use picometers (106 pm) or nanometers (0.106 nm) rather than micrometers or millimeters. We choose the prefix multiplier that is most convenient for a particular number.

Conceptual Connection E.1 Prefix Multipliers

Units of Volume

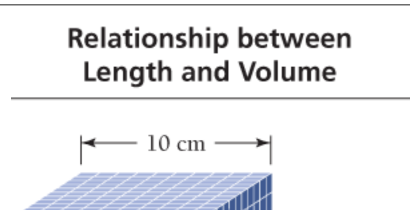
Many scientific measurements require combinations of units. For example, velocities are often reported in units such as km/s, and densities are often reported in units of g/cm^3. Both of these units are **derived units**, combinations of other units. An important SI-derived unit for chemistry is the m^3, used to report measurements of volume.

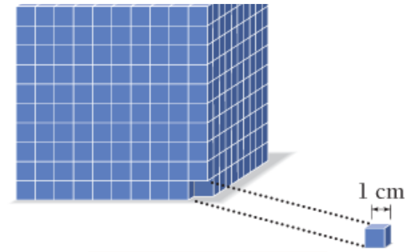
Volume is a measure of space. Any unit of length, when cubed (raised to the third power), becomes a unit of volume. The cubic meter (m^3), cubic centimeter (cm^3), and cubic millimeter (mm^3) are all units of volume. The cubic nature of volume is not always intuitive, and studies have shown that our brains are not naturally wired to think abstractly, which we need to do in order to think about volume. For example, consider this question: How many small cubes measuring 1 cm on each side are required to construct a large cube measuring 10 cm (or 1 dm) on a side?

The answer to this question, as we can see by carefully examining the unit cube in Figure E.3, is 1000 small cubes. When we go from a linear, one-dimensional distance to a three-dimensional volume, we must raise both the linear dimension *and* its unit to the third power (not just multiply by 3). The volume of a cube is equal to the length of its edge cubed:

$$\text{volume of cube} = (\text{edge length})^3$$

Figure E.3 **The Relationship between Length and Volume**





A 10-cm cube contains 1000 1-cm cubes.

A cube with a 10-cm edge length has a volume of $(10\ \text{cm})^3$ or $1000\ \text{cm}^3$, and a cube with a 100-cm edge length has a volume of $(100\ \text{cm}^3) = 1,000,000\ \text{cm}^3$. Other common units of volume in chemistry are the **liter (L)** and the **milliliter (mL)**. One milliliter $(10^{-3}\ \text{L})$ is equal to $1\ \text{cm}^3$. A gallon of gasoline contains 3.785 L. Table E.3 lists some common units for volume and their equivalents.

Table E.3 **Common Units for Volume and Their Equivalents**

1 liter (L) = 1000 mL = 1000 cm^3
1 liter (L) = 1.057 quarts (qt)
1 U.S. gallon (gal) = 3.785 liters (L)