5.9: Essential Skills 4

Learning Objectives

- Temperature
- Unit Conversions: Dimensional Analysis

The previous Essential Skills sections introduced some fundamental operations that you need to successfully manipulate mathematical equations in chemistry. This section describes how to convert between temperature scales and further develops the topic of unit conversions started in Essential Skills 2 .

Temperature

The concept of temperature may seem familiar to you, but many people confuse temperature with heat. **Temperature** is a measure of how hot or cold an object is relative to another object (its thermal energy content), whereas **heat** is the flow of thermal energy between objects with different temperatures.

Science only uses SI and derived units with few if any exceptions. Therefore this text avoids conversions between customary units (foot, pound, Farenheit) that are simply inappropriate and only used in a few countries.

Two different scales are commonly used to measure temperature: Celsius (°C), and Kelvin (K). Thermometers measure temperature by using materials that expand or contract when heated or cooled. Mercury or alcohol thermometers, for example, have a reservoir of liquid that expands when heated and contracts when cooled, so the liquid column lengthens or shortens as the temperature of the liquid changes.

The Celsius Scale

The Celsius scale was developed in 1742 by the Swedish astronomer Anders Celsius. It is based on the melting and boiling points of water under normal atmospheric conditions. The current scale is an inverted form of the original scale, which was divided into 100 increments. Because of these 100 divisions, the Celsius scale is also called the *centigrade scale*.

The Kelvin Scale

Lord Kelvin, working in Scotland, developed the Kelvin scale in 1848. His scale uses molecular energy to define the extremes of hot and cold. Absolute zero, or 0 K, corresponds to the point at which molecular energy is at a minimum. The Kelvin scale is preferred in scientific work, although the Celsius scale is also commonly used. Temperatures measured on the Kelvin scale are reported simply as K, not °K.

Converting between Scales

The kelvin is the same size as the Celsius degree, so measurements are easily converted from one to the other. The freezing point of water is 0°C = 273.15 K; the boiling point of water is 100°C = 373.15 K. The Kelvin and Celsius scales are related as follows:

$$T\,(in^{o}C) + 273.15 = T\,(in\ K) \tag{5.9.1}$$

$$T\,(in\ K) - 273.15 = T\,(in^{o}C) \tag{5.9.2}$$

Skill Builder ES1

1. Convert the temperature of the surface of the sun (5800 K) and the boiling points of gold (3080 K) and liquid nitrogen (77.36 K) to °C .

Solution:

1. Sun: 5800 K = (5800 -273.15) ^{o}C = 5527 ^{o}C

Liquid Gold: 3080 K = (3080 -273.15) ^{o}C =2807 ^{o}C

Liquid N_2 77.36 K = (77.36 -274.15) ^{o}C = -195.79 ^{o}C

Unit Conversions: Dimensional Analysis

In Essential Skills 2, you learned a convenient way of converting between units of measure, such as from grams to kilograms or seconds to hours. The use of units in a calculation to ensure that we obtain the final proper units is called *dimensional analysis*. For example, if we observe experimentally that an object's potential energy is related to its mass, its height from the ground, and to a gravitational force, then when multiplied, the units of mass, height, and the force of gravity must give us units corresponding to those of energy.

Energy is typically measured in joules, calories, or electron volts (eV), defined by the following expressions:

$$1\ J = 1\ \left(kg \cdot m^2\right)/s^2 = 1\ coulomb \cdot volt \tag{5.9.3}$$

$$1\ cal = 4.184\ J \tag{5.9.4}$$

$$1 eV = 1.602 \times 10^{-19} J \tag{5.9.5}$$

To illustrate the use of dimensional analysis to solve energy problems, let us calculate the kinetic energy in joules of a 320 g object traveling at 123 cm/s. To obtain an answer in joules, we must convert grams to kilograms and centimeters to meters. Using Equation 5.1.5, the calculation may be set up as follows:

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}(g)\left[\left(\frac{cm}{s}\right)\left(\frac{cm}{s}\right)\right]^2 \tag{5.9.6}$$

$$= \left(\cancel{g}\right)\left(\frac{kg}{\cancel{g}}\right)\left(\frac{\cancel{cm^2}}{s^2}\right)\left(\frac{m^2}{\cancel{cm^2}}\right) = \frac{kg \cdot m^2}{s^2} \tag{5.9.7}$$

$$= \frac{1}{2}320\ \cancel{g}\left(\frac{1\ kg}{1000\ \cancel{g}}\right)\left[\left(\frac{123\ \cancel{cm}}{1\ s}\right)\left(\frac{1\ m}{100\ \cancel{cm}}\right)\right]^2 = \frac{0.320\ kg}{2}\left[\frac{123\ m}{s\,(100)}\right]^2 \tag{5.9.8}$$

$$= 0.242\ kg \cdot m^2/s^2 = 0.242\ J \tag{5.9.9}$$

Alternatively, the conversions may be carried out in a stepwise manner:

$$320\ \cancel{g}\left(\frac{1\ kg}{1000\ \cancel{g}}\right) = 0.320\ kg \tag{5.9.10}$$

$$123\ \cancel{cm}\left(\frac{1\ m}{100\ \cancel{cm}}\right) = 1.23\ m \tag{5.9.11}$$

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}(g)\left[\left(\frac{cm}{s}\right)\left(\frac{cm}{s}\right)\right]^2 \tag{5.9.12}$$

$$KE = \frac{1}{2}(0.320 kg)\left(\frac{1.23\ m}{s}\right)^2 = 0.242\ \left(kg \cdot m^2/s^2\right) = 0.242\ J \tag{5.9.13}$$

However, this second method involves an additional step

A small discrepancy between answers using the different methods might be expected due to rounding to the correct number of significant figures for each step when carrying out the calculation in a stepwise manner. Recall that all digits in the calculator should be carried forward when carrying out a calculation using multiple steps. In this problem, we first converted kilocalories to kilojoules and then converted ounces to grams. Skill Builder ES2 allows you to practice making multiple conversions between units in a single step.

Skill Builder ES2

1. Write a single equation to show how to convert cm/min to km/h; °C/s to K/h.

Solution:

1. $$[\left(\frac{\cancel{cm}}{\cancel{min}}\right)\left(\frac{1\ \cancel{m}}{100\ \cancel{cm}}\right)\left(\frac{1\ km}{1000\ \cancel{m}}\right)\left(\frac{60\ \cancel{min}}{1\ h}\right) = km/h \tag{5.9.14}$$

$$\left(\frac{{}^{o}C}{\cancel{s}}\right)\left(\frac{60\ \ \cancel{s}}{1\ \ \cancel{min}}\right)\left(\frac{60\ \ \cancel{min}}{h}\right)+273.15\ K=K/h \tag{5.9.15}$$

Contributors

- Anonymous

Modified by Joshua Halpern