Learning Objectives

• Identify the appropriate metric unit for measuring items of various dimensions.

• Solve dimensional analysis using metric and English units. (note: metric unit definitions will not be provided on quiz.)

Measurements provide the macroscopic information that is the basis of most of the hypotheses, theories, and laws that describe the behavior of matter and energy in both the macroscopic and microscopic domains of chemistry. Every measurement provides three kinds of information: the size or magnitude of the measurement (a number); a standard of comparison for the measurement (a unit); and an indication of the uncertainty of the measurement. While the number and unit are explicitly represented when a quantity is written, the uncertainty is an aspect of the measurement result that is more implicitly represented and will be discussed later.

The number in the measurement can be represented in different ways, including decimal form and scientific notation. For example, the maximum takeoff weight of a Boeing 777-200ER airliner is 298,000 kilograms, which can also be written as $2.98 \times 10^5$ kg. The mass of the average mosquito is about 0.0000025 kilograms, which can be written as $2.5 \times 10^{-6}$ kg.

Units, such as liters, pounds, and centimeters, are standards of comparison for measurements. When we buy a 2-liter bottle of a soft drink, we expect that the volume of the drink was measured, so it is two times larger than the volume that everyone agrees to be 1 liter. The meat used to prepare a 0.25-pound hamburger is measured so it weighs one-fourth as much as 1 pound. Without units, a number can be meaningless, confusing, or possibly life threatening. Suppose a doctor prescribes phenobarbital to control a patient’s seizures and states a dosage of “100” without specifying units. Not only will this be confusing to the medical professional giving the dose, but the consequences can be dire: 100 mg given three times per day can be effective as an anticonvulsant, but a single dose of 100 g is more than 10 times the lethal amount.

We usually report the results of scientific measurements in SI units, an updated version of the metric system, using the units listed in Table 1. Other units can be derived from these base units. The standards for these units are fixed by international agreement, and they are called the International System of Units or SI Units (from the French, Le Système International d’Unités). SI units have been used by the United States National Institute of Standards and Technology (NIST) since 1964.

<table>
<thead>
<tr>
<th>Property Measured</th>
<th>Name of Unit</th>
<th>Symbol of Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>meter</td>
<td>m</td>
</tr>
<tr>
<td>mass</td>
<td>kilogram</td>
<td>kg</td>
</tr>
<tr>
<td>time</td>
<td>second</td>
<td>s</td>
</tr>
<tr>
<td>temperature</td>
<td>kelvin</td>
<td>K</td>
</tr>
</tbody>
</table>
Sometimes we use units that are fractions or multiples of a base unit. Ice cream is sold in quarts (a familiar, non-SI base unit), pints (0.5 quart), or gallons (4 quarts). We also use fractions or multiples of units in the SI system, but these fractions or multiples are always powers of 10. Fractional or multiple SI units are named using a prefix and the name of the base unit. For example, a length of 1000 meters is also called a kilometer because the prefix *kilo* means “one thousand,” which in scientific notation is $10^3$ (1 kilometer = 1000 m = $10^3$ m). The prefixes used and the powers to which 10 are raised are listed in Table 2:

**Table 2: Common Unit Prefixes**

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Symbol</th>
<th>Factor</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>angstrom</td>
<td>Å</td>
<td>$10^{-10}$</td>
<td>5 angstrom ($\text{Å}$) = $5 \times 10^{-10}$ m (0.0000000001 m)</td>
</tr>
<tr>
<td>nano</td>
<td>n</td>
<td>$10^{-9}$</td>
<td>1 nanogram (ng) = $1 \times 10^{-9}$ g (0.000000001 g)</td>
</tr>
<tr>
<td>micro</td>
<td>µ</td>
<td>$10^{-6}$</td>
<td>1 microliter ($\mu$L) = $1 \times 10^{-6}$ L (0.000001 L)</td>
</tr>
<tr>
<td>milli</td>
<td>m</td>
<td>$10^{-3}$</td>
<td>2 millimoles (mmol) = $2 \times 10^{-3}$ mol (0.002 mol)</td>
</tr>
<tr>
<td>centi</td>
<td>c</td>
<td>$10^{-2}$</td>
<td>7 centimeters (cm) = $7 \times 10^{-2}$ m (0.07 m)</td>
</tr>
<tr>
<td>deci</td>
<td>d</td>
<td>$10^{-1}$</td>
<td>1 deciliter (dL) = $1 \times 10^{-1}$ L (0.1 L)</td>
</tr>
<tr>
<td>kilo</td>
<td>k</td>
<td>$10^3$</td>
<td>1 kilometer (km) = $1 \times 10^3$ m (1000 m)</td>
</tr>
<tr>
<td>mega</td>
<td>M</td>
<td>$10^6$</td>
<td>3 megahertz (MHz) = $3 \times 10^6$ Hz (3,000,000 Hz)</td>
</tr>
</tbody>
</table>

**SI Base Units**

The initial units of the metric system, which eventually evolved into the SI system, were established in France during the French Revolution. The original standards for the meter and the kilogram were adopted there in 1799 and eventually by other countries. This section introduces four of the SI base units commonly used in chemistry. Other SI units will be introduced in subsequent chapters.
Length

The standard unit of length in both the SI and original metric systems is the meter (m). A meter was originally specified as 1/10,000,000 of the distance from the North Pole to the equator. It is now defined as the distance light in a vacuum travels in 1/299,792,458 of a second. A meter is about 3 inches longer than a yard (Figure \(\PageIndex{1}\)); one meter is about 39.37 inches or 1.094 yards. Longer distances are often reported in kilometers (1 km = 1000 m = \(10^3\) m), whereas shorter distances can be reported in centimeters (1 cm = 0.01 m = \(10^{-2}\) m) or millimeters (1 mm = 0.001 m = \(10^{-3}\) m).

Mass

The standard unit of mass in the SI system is the kilogram (kg). A kilogram was originally defined as the mass of a liter of water (a cube of water with an edge length of exactly 0.1 meter). In 1889, it was redefined by a certain cylinder of platinum-iridium alloy, which was kept in France (Figure \(\PageIndex{2}\)). Any object with the same mass as this cylinder was said to have a mass of 1 kilogram (which can lead to uncertainties unacceptable to the precision of modern instrumentation). One kilogram is about 2.2 pounds. The gram (g) is exactly equal to 1/1000 of the mass of the kilogram (\(10^{-3}\) kg). Over the past 100 years, the IPK has lost 50 millionths of a gram - a seemingly negligible amount, but something that has caused it to be lighter - or all standard replicas to be heavier - and changing the definition of a kilogram in the process. As all balances in the world are standardized to this value, it is important that this value, itself, be standard. On May 20, 2019, a new definition will be used for the kilogram, based on the unchanging Planck's constant.\(^1\)
Figure \(\PageIndex{2}\): This replica prototype kilogram is housed at the National Institute of Standards and Technology (NIST) in Maryland. (credit: National Institutes of Standards and Technology).
Temperature

Temperature is an intensive property. The SI unit of temperature is the kelvin (K). The IUPAC convention is to use kelvin (all lowercase) for the word, K (uppercase) for the unit symbol, and neither the word “degree” nor the degree symbol (°). The degree Celsius (°C) is also allowed in the SI system, with both the word “degree” and the degree symbol used for Celsius measurements. Celsius degrees are the same magnitude as those of kelvin, but the two scales place their zeros in different places. Water freezes at 273.15 K (0 °C) and boils at 373.15 K (100 °C) by definition, and normal human body temperature is approximately 310 K (37 °C). The conversion between these two units and the Fahrenheit scale will be discussed later in this chapter.

Time

The SI base unit of time is the second (s). Small and large time intervals can be expressed with the appropriate prefixes; for example, 3 microseconds = 0.000003 s = 3 $\times 10^{-6}$ and 5 megaseconds = 5,000,000 s = 5 $\times 10^6$ s. Alternatively, hours, days, and years can be used.

Volume

Volume is the measure of the amount of space occupied by an object. The standard SI unit of volume is defined by the
base unit of length (Figure \(\PageIndex{3}\)). The standard volume is a cubic meter (m^3), a cube with an edge length of exactly one meter. To dispense a cubic meter of water, we could build a cubic box with edge lengths of exactly one meter. This box would hold a cubic meter of water or any other substance.

A more commonly used unit of volume is derived from the decimeter (0.1 m, or 10 cm). A cube with edge lengths of exactly one decimeter contains a volume of one cubic decimeter (dm^3). A liter (L) is the more common name for the cubic decimeter. One liter is about 1.06 quarts. A cubic centimeter (cm^3) is the volume of a cube with an edge length of exactly one centimeter. The abbreviation cc (for cubic centimeter) is often used by health professionals. A cubic centimeter is also called a milliliter (mL) and is 1/1000 of a liter.

<Figure \(\PageIndex{3}\): (a) The relative volumes are shown for cubes of 1 m^3, 1 dm^3 (1 L), and 1 cm^3 (1 mL) (not to scale). (b) The diameter of a dime is compared relative to the edge length of a 1-cm^3 (1-mL) cube.

Summary

Measurements provide quantitative information that is critical in studying and practicing chemistry. Each measurement has an amount, a unit for comparison, and an uncertainty. Measurements can be represented in either decimal or scientific notation. Scientists primarily use the SI (International System) or metric systems. We use base SI units such as meters, seconds, and kilograms, as well as derived units, such as liters (for volume) and g/cm^3 (for density). In many cases, we find it convenient to use unit prefixes that yield fractional and multiple units, such as microseconds (10^{-6} seconds) and megahertz (10^6 hertz), respectively.

Glossary

**Celsius (°C)**

unit of temperature; water freezes at 0 °C and boils at 100 °C on this scale

cubic centimeter (cm^3 or cc)

volume of a cube with an edge length of exactly 1 cm
cubic meter \((m^3)\)
- SI unit of volume

kelvin \((K)\)
- SI unit of temperature; \(273.15 \, K = 0 \, ^\circ C\)

kilogram \((kg)\)
- standard SI unit of mass; \(1 \, kg = \text{approximately } 2.2 \, \text{pounds}\)

length
- measure of one dimension of an object

liter \((L)\)
- (also, cubic decimeter) unit of volume; \(1 \, L = 1,000 \, cm^3\)

meter \((m)\)
- standard metric and SI unit of length; \(1 \, m = \text{approximately } 1.094 \, \text{yards}\)

milliliter \((mL)\)
- \(1/1,000\) of a liter; equal to \(1 \, cm^3\)

second \((s)\)
- SI unit of time

**SI units (International System of Units)**
- standards fixed by international agreement in the International System of Units (Le Système International d’Unités)

unit
- standard of comparison for measurements

volume
- amount of space occupied by an object

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**Contributors**

- Paul Flowers (University of North Carolina - Pembroke), Klaus Theopold (University of Delaware) and Richard Langley (Stephen F. Austin State University) with contributing authors. Textbook content produced by OpenStax College is licensed under a [Creative Commons Attribution License 4.0](http://creativecommons.org/licenses/by/4.0) license. Download for free at [http://cnx.org/contents/85abf193-2bd...a7ac8df6@9.110](http://cnx.org/contents/85abf193-2bd...a7ac8df6@9.110).
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