Metric System

The metric system is used in the sciences, and it has the following units for measurement:

unit	symbol	measures
meter	m	length
gram	g	mass
liter	L	volume
second	s	time

It uses powers of 10 to increase or decrease the above units for measurement. The prefixes (along with symbols, powers of ten, and the meaning) that are commonly used in chemistry appear in the table below.

prefix	symbol	value		meaning
giga	G	$1x10^9$	1,000,000,000	billion
mega	M	$1x10^6$	1,000,000	million
kilo	k	$1x10^3$	1,000	thousand
----------- base unit -------------------			1	one
deci	d	$1x10^{-1}$	0.1	tenth
centi	c	$1x10^{-2}$	0.01	hundredth
milli	m	$1x10^{-3}$	0.001	thousandth
micro	μ	$1x10^{-6}$	0.000001	millionth
nano	n	$1x10^{-9}$	0.000000001	billionth
pico	p	$1x10^{-12}$		trillionth

The prefixes are combined with the base units or the prefix symbols are combined with the unit symbols. Using the chart above along with the base units, one gigameter (written Gm) equals $1x10^9$m. Written as an equality, this is 1Gm = $1x10^9$m. Other equalities that come from the above charts include 1kg=$1x10^3$g, 1mL=$1x10^{-3}$L, 1 μg=$1x10^{-6}$g, and 1ns=$1x10^{-9}$s. In words, the last equality states that one nanosecond is equal to $1x10^{-9}$ seconds.

Unit Analysis Method and Problem Solving

Equalities can be written as unit factors. For example, the equality 1Gm = $1x10^9$m can be written as these two factors

$$\frac{1\text{Gm}}{1x10^9\text{m}} \quad \text{or} \quad \frac{1x10^9\text{m}}{1\text{Gm}}$$

Last lecture, we used unit factors to convert one set units into another with the unit analysis method. The three steps are: 1) write the units of the answer, 2) write the starting data, and 3) apply unit factors to convert the starting data to the units of the answer. When one of the units in a metric conversion is a base unit, the solution can be done in one step.

Example: Convert 27μm to m
Solution: 1) m, 2) 27μm, 3) From the chart, $1\mu m = 1x10^{-6}m$

$$\frac{27\mu m}{1} \text{ X } \frac{1x10^{-6}m}{1\mu m} = 0.000027m$$

The starting measurement has 2 significant digits (SD), so the answer has 2SD.

When neither the starting nor ending unit in a metric conversion is the base unit, the solution takes two steps.

Example: Convert 1.83kg to dg
Solution: 1) dg, 2) 1.83kg, 3) From the chart, $1kg=1x10^{3}g$ and $1dg=1x10^{-1}g$. Note that both unit equations have one side that goes to the base unit. One equation converts the starting metric unit to the base unit, while the second coverts the base unit to the units in the answer as follows:

$$\frac{1.83kg}{1} \text{ X } \frac{1x10^{3}g}{1kg} \text{ X } \frac{1dg}{1x10^{-1}g} = 18300dg\ (3SD) = 1.83x10^{4}dm$$

Example: A solar mass (mass of the sun) is $1.989x10^{30}kg$. Convert this to Gg
Solution: 1) Gg, 2) $1.989x10^{30}kg$, 3) From the chart, $1Gg=1x10^{9}g$, $1kg=1x10^{3}g$.

$$\frac{1.989x10^{30}kg}{1} \text{ X } \frac{1x10^{3}g}{1kg} \text{ X } \frac{1Gg}{1x10^{9}g} = 1.989x10^{24}Gg(4SD)$$

The British system of units is commonly used in the US. Values in the British system must often be converted to the metric system in the sciences.

unit	symbol	measures	Conversion to metric
inch	in	length	1in = 2.54cm (exact by definition)
pound	lb	mass	1lb = 454g (3SD)
quart	qt	volume	1qt = 0.946L (3SD)
second	s	time	1s (British) = 1.00s (3SD)

Example: Which measurement is more 1qt or 1L?
Solution: Use the chart above to convert them both to the same unit to compare (convert qt to L)

$$\frac{1qt}{1} \text{ X } \frac{0.946L}{1qt} = 0.946L$$

1qt is 0.946L, so 1qt is less than 1L.

Example: Convert 3.25qt to mL
Solution: 1) mL, 2) 3.25qt, 3) 1qt=0.946L, 1mL=1x10^{-3}L.

$$\frac{3.25\text{qt}}{1} \text{ X } \frac{0.946\text{L}}{1\text{qt}} \text{ X } \frac{1\text{mL}}{1\text{x}10^{-3}\text{L}} = 3074.5\text{mL (3SD)} = 3070\text{mL}$$

A compound unit has units in both the numerator and the denominator. Many scientific quantities, such as meters/second (m/s) and grams/milliliter (g/mL) have compound units. When the both units differ between the starting information and the answer, converting units requires at least two steps. Using the 3-step unit analysis approach, follow a methodical process by converting the units of the numerator first and then the denominator.

Example: A European sportscar travels at 32m/s. Convert this speed to kilometers per hour (km/hr).
Solution: Start with the given quantity, 32m/s (there is no lab measurable), then use the conversion factors of 1km=1x10^{3}m and 1hr=3600s to do the conversion. The answer has two SD because the starting data has two SD and the solution uses only the multiply/divide rule.

$$\frac{32\text{m}}{1\text{s}} \text{ X } \frac{1\text{km}}{1\text{x}10^{3}\text{m}} \text{ X } \frac{3600\text{s}}{1\text{hr}} = \frac{115.2\text{ km}}{\text{hr}} = 120\text{km/hr (2SD)}$$

Note: Using the conversion factor of 1mi=1.60km, we could convert the above answer to miles/hr. See if you can do this. Remember to keep all the digits and round the final answer. (The correct answer is 72miles/hr. If you round **incorrectly**, you get an answer of 75miles/hr).

Volume and Density Calculations
Volume is the amount of space something takes up, which we can calculate by measuring for rectangular solids. The volume (V) of a rectangular solid = length (l) X width (w) X thickness (t), where the measurements of length, width, and thickness must all be in the same units.

Example: A rectangular solid measures has a length of 1.55cm, a width of 4.50cm, and a thickness of 0.9mm. Calculate the volume.
Solution: Convert thickness into centimeters, then calculate the volume as V= l X w X t.

$$\frac{0.9\text{mm}}{1} \text{ X } \frac{1\text{x}10^{-3}\text{m}}{1\text{mm}} \text{ X } \frac{1\text{cm}}{1\text{x}10^{-2}\text{m}} = 0.09\text{cm (Note 1SD).}$$

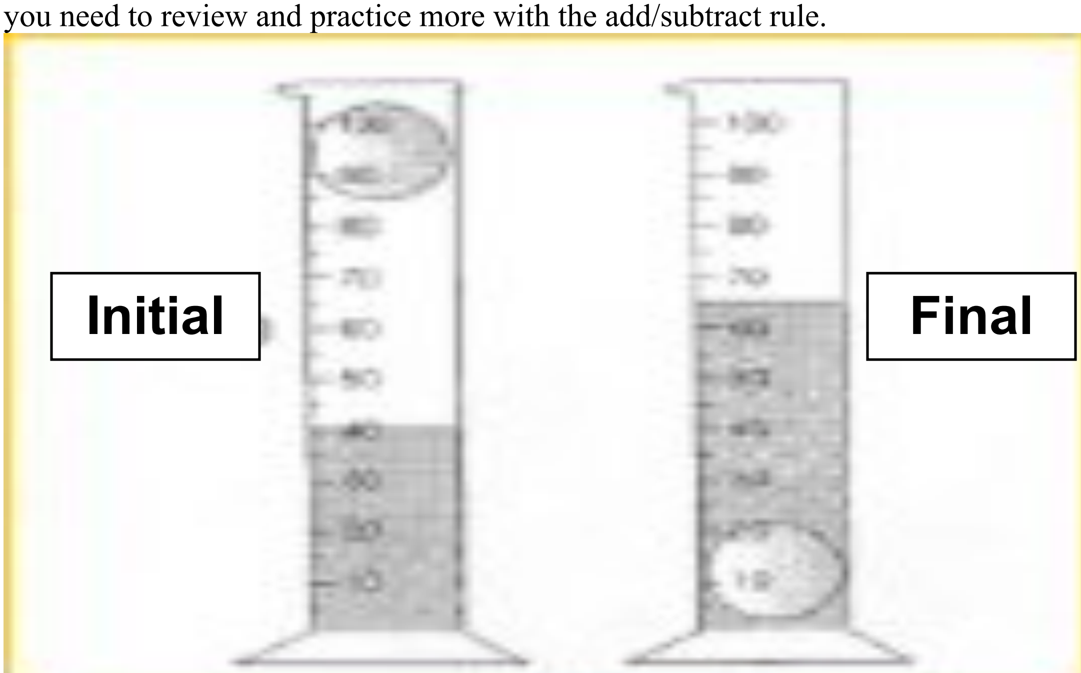
V= 1.55cm X 4.50cm X 0.09cm = 0.62775cm^{3} (1SD) = 0.6cm^{3}

Because 1L is equal to 1000 cubic centimeters (cm^3) by a scientific definition, we know that $1mL = 1cm^3$. In other words, a volume measurement in milliliters would have the same numerical value as a volume measurement in cm^3. Using the unit factor $1cm^3/1mL$ and the unit analysis method, 7.25mL is equal to $7.25cm^3$. It will be helpful for you to memorize that $\mathbf{1mL = 1cm^3}$, and to then use the appropriate unit factor with the unit analysis method to solve problems of scientific interest. This defined relationship between length (cm) and volume (mL) helps to solve other problems using an appropriate conversion factor.

Example: A soda can contains $455cm^3$ of soda. What is this volume in cubic inches (in^3) using 1in=1.54cm?
Solution: Apply the conversion factor 1in/2.54cm three times to convert cm^3 to in^3.

$$\frac{455cm^3}{1} \text{ X } \frac{1in}{2.54cm} \text{ X } \frac{1in}{2.54cm} \text{ X } \frac{1in}{2.54cm} = 27.765804in^3 \text{ (3SD)} = 27.8in^3.$$

Another approach to measure volume of a solid is by the volume displaced by dropping the object into water. In the picture below, the marble displaces about 25.0mL of water. The initial volume of water is about 40.0mL. The final volume of water is about 65.0mL. The volume of the marble is V_{final}-$V_{initial}$ = 65.0mL-40.0mL = 25.0mL (3SD by add/subtract rule). Note: using a different example with $V_{initial}$=40.5mL and V_{final}=42.0mL, the volume displaced would be V_{final}-$V_{initial}$ = 42.0mL-40.5mL = 1.5mL (2SD by add/subtract rule). If you do not get the correct number of SD for this example, you need to review and practice more with the add/subtract rule.



To calculate the density of a sample, divide the mass of the sample (usually in grams) by the volume of the sample (usually in mL for liquids, cm^3 for solids, and L for gases). The equation to calculate density is: density(d)=mass(m)/volume(V).

One way to estimate the density of a solid is to determine whether that solid floats or sinks in a liquid of known density. For example, ice floats on water (density=1.00g/mL), so ice must have a density that is less than 1.00g/mL. A marble sinks in water (density=1.00g/mL), so that marble must have a density that is greater than 1.00g/mL. By floating or sinking a solid on liquids of different, known densities, the density of the solid can be bracketed (estimated to be between two values).

Measuring the mass and the volume of a sample provides the measurements to calculate density.

Example: An aluminum nugget with a mass of 6.502g displaces a volume of water equal to 2.40mL. Calculate the density of the aluminum nugget.
Solution: The units of density for solids are g/mL (or the formula is d=m/V). Using unit analysis (or the formula), we get:

d= 6.502g / 2.40mL = 2.709166667g/mL (3SD) = 2.71g/mL

Density is a unit factor that can be used to solve problems of chemical interest.

Example: An aluminum nugget (density=2.703g/mL) displaces 13.55mL of water. What is the mass of the aluminum nugget?
Solution: Start with the lab measurable (mL). Use density as a unit factor to convert to the desired units.

$$\frac{13.55\text{mL}}{1} \text{ X } \frac{2.703\text{g}}{\text{mL}} = 36.62565\text{g (4SD)} = 36.63\text{g.}$$

Temperature and Heat

Temperature measures the average motion, or kinetic energy, in a sample. Sciences use the Celsius (°C) and Kelvin (K) temperature scales. When temperatures are recorded in the Fahrenheit (°F) scale, they must usually be converted to Celsius. For reference, the table below lists the temperatures at which water freezes and boils on the three scales:

Water	Celsius	Fahrenheit	Kelvin
Freezes	0°C	32°F	272K
Boils	100°C	212°F	373K

To convert Celsius temperatures to Fahrenheit, use the following equation:

°C = (°F-32) /1.8

To convert Fahrenheit temperatures to Celsius, use the following equation:

°F = 1.8 °C + 32

To convert from Celsius to Kelvin, add 273 to the Celsius temperature

K= °C + 273

Example: Body temperature is 98.6°F. Convert this to Celsius and Kelvin.
Solution: °C = (°F-32) / 1.8 = (98.6-32) / 1.8 = 37.0°C (3D)

$$K = °C + 273 = 37.0 + 273 = 310K \text{ (3SD by add/subtract rule)}$$

Heat, measured in Joules (J) or calories, measures the energy content of a system (rather than the motion). Heat depends on temperature. Two different substances with the same temperature would be expected to possess different heats because heat content depends on the temperature, the mass of the substance, and the type of substance. For example, an adult (large) and a child (small) with the same body temperature would have different heats. The adult would have more heat because the adult has more mass. Heat also depends on the type of substance. For example, take 1g of water and 1g of iron at 100°C. Water holds more heat per gram than iron (can be looked up in tables as specific heat capacity), so the 1g of water holds more heat than 1g of iron. As a result, 1g of water at 100°C would cause more burns to skin than 1g of iron at 100°C.