CHEM 0094 **MEASUREMENT**

1. **Units**

The basis of all science is measurement. All measurement involves comparing the quantity being measured to a **standard**. Saying an object has a mass of (weighs) 60 grams means that its mass is 60 times a standard quantity we define as 1 gram. Thus, a measurement has two components, a **magnitude** (the number) and a **unit** (in this case, grams; abbreviated g). The measurement would be completely meaningless if either the magnitude or the unit was omitted. One **system** of units is called the **metric** system because it uses the metre (*or* meter) as the unit of length. A particular version of the metric system used in science is called the ***SI*** system (see Table 2.1 for some of the fundamental units used in ***SI***). Prefixes which indicate powers of 10 are used to convert the fundamental units into larger or smaller units. Some of these are given in Table 2.2. Another useful prefix is **giga** (G, meaning 1,000,000,000 or 10^9). These should all be **MEMORIZED**.

2. **Length** (l)

The unit of length used in science is the metre (m). 1 metre used to be defined as $1/10^7$ of the distance from the equator to the north pole and later in terms of a standard platinum-iridium bar kept at Sèvres, France. In 1983, the metre was defined as the distance travelled by light in a vacuum in 1/299,792,458 of a second. Commonly used subunits are **kilometre**, **centimetre**, **millimetre**, **micrometre and nanometre**. Various instruments for measuring length will be used in the lab.

3. **Volume** (V)

Volume is not a fundamental unit; it is a **derived** unit (also called cubic measure) whose dimensions are $l \times l \times l = l^3$. The formulas for volumes of some regular objects are given below.
cube: $V = l^3$ (l = length of side); **rectangular solid**: $V = a \times b \times c$
sphere: $V = 4/3\pi r^3$ (r = radius = $\frac{1}{2}$ x diameter); **cylinder**: $V = \pi r^2 h$ (h = height)
For solids, usually use l in cm; hence V in cm^3

(a) Calculate the volume of a cube of side 24.5 cm. (*Ans*. 1.47×10^4 cm^3)
(b) Calculate the volume of a sphere of diameter 4.66 cm. (*Ans*. 53.0 cm^3)
(c) Calculate the volume of a cylinder of diameter 6.28 cm and height 7.85 cm. (*Ans*. 243 cm^3)
(d) Calculate the length of the side of a cube of volume 45.0 cm^3. (*Ans*. 3.56 cm)
(e) Calculate the height of a cylinder of volume 78.5 cm^3 and diameter 2.40 cm. (*Ans*. 17.4 cm)
(f) Calculate the diameter of a cylinder of volume 488 cm^3 and height 62.8 cm. (*Ans*. 3.15 cm)
(g) Calculate the diameter of a sphere of volume 118 cm^3. (*Ans*. 6.09 cm)

For liquids, litres (L) are used for volume measurement. 1 L is defined as the volume of a cube of side 1 dm (10 cm). The volume of 1 L is therefore $(10\ cm)^3$, or 10^3 cm^3, or 1000 cm^3. For small volumes, millilitres (mL) are used. 1 mL = 10^{-3} L or 1000 mL = 1 L.
Hence, 1000 mL = 1000 cm^3 and 1 mL = 1 cm^3.

For irregular solids, volume can be measured by **displacement** of a liquid, provided the solid does not (a) react with, (b) be absorbed by, or (c) float in, the liquid.

Various instruments for measuring the volume of liquids will be used in the lab.

4. **Mass** (M)
Mass is a measure of the amount of matter in a substance or object. Weight is the force that gravity exerts on mass. Although units of mass are named on the basis of the **gram**, the fundamental unit of mass is the **kilogram**. Other commonly used subunits are **milligram**, **microgram** and **nanogram**. Various instruments for measuring mass will be used in the lab.

5. **Uncertainty in Measurement - Significant Figures**
There is uncertainty in any measurement. Usually, all digits but the last are reliable but the last digit is estimated. For a reported length of 10.54 cm, the 10.5 is definite but the 4 is estimated. Although the 4 is estimated, it is meaningful (*or* **significant**) because we can usually be sure that it is close to 4 and definitely not, say, 1 or 9. The measurement therefore contains **four *significant figures***. The more significant figures (sig figs) in a measurement, the more accurate is the measurement. An example of the same volume of a liquid measured with different graduated cylinders will be discussed in class. The rules for counting the number of sig figs and for the number of sig figs after a calculation will also be discussed.
N.B.: There is no uncertainty in counted numbers or defined relationships.

(a) How many sig figs are there in 345.78 g? (*Ans*. 5)
(b) How many sig figs are there in 50.0602 cm? (*Ans*. 6)
(c) How many sig figs are there in 80.4700 g? (*Ans*. 6)
(d) How many sig figs are there in 0.0078 mL? (*Ans*. 2)
(e) How many sig figs are there in 450 g? (*Ans*. cannot tell)
(f) How many sig figs are there in $\frac{4.2202 \times 10^3 \ \times \ 0.050}{365}$? (*Ans*. 2; 0.58)
(g) How many sig figs are there in 96.0 + 5.27 + 0.095? (*Ans*. 4; 101.4)

6. **Unit Conversion** (*or* Factor-Label Method, *or* Dimensional Analysis) $\frac{a}{a} = 1$ If a = b,

$\frac{a}{b} = 1$ and $\frac{b}{a} = 1$

a = b is an **equality** or **equivalence**; $\frac{a}{b}$ and $\frac{b}{a}$ are **conversion factors**

Muliplying anything by 1 does not change it. Therefore, if a = b, c = c x $\frac{a}{b}$

This can be used to convert a measurement from one unit to another and is also very useful in solving a wide range of problems.

For example, convert 15.5 cm to inches (in), given that 1 in = 2.54 cm (exactly).

The conversion factors are $\frac{2.54 \text{ cm}}{1 \text{ in}}$ and $\frac{1 \text{ in}}{2.54 \text{ cm}}$. For this problem, we would use the second factor because we want to find the number of inches.

No. of inches = $15.5 \text{ cm} \times \frac{1 \text{ in}}{2.54 \text{ cm}} = 6.10 \text{ in}$

Note that we can cancel the *cm* on top with the *cm* on the bottom, leaving *in* as the unit.

$$15.5\ \not{cm} \times \frac{1\ in}{2.54\ \not{cm}} = 6.10\ in$$

Using the first factor gives $15.5\ cm \times \frac{2.54\ cm}{1\ in} = 39.4\ cm^2/in$ which is meaningless.

Some equivalences are implied by prefixes which must be known. Other equivalences will be given. Often, more than one factor is needed.

(a) Convert 4835 g to kg. (*Ans*. 4.835 kg)
(b) Convert 5.78×10^2 km to cm. (*Ans*. 5.78×10^7 cm)
(c) Convert 28.0 L to gallons (Can.). 4.55 L = 1 gal. (*Ans*. 6.15 gal)
(d) How many kilometres make exactly 1 mile? (1 mile = 5280 ft; 12 in = 1 ft) (*Ans*. 1.609344 km)

To convert units of area or volume, square or cube the linear relationship. For example, convert 48.6 in^2 to cm^2.
1 in = 2.54 cm, therefore $(1\ in)^2 = (2.54\ cm)^2$ or $1\ in^2 = 2.54^2\ cm^2$.

$$48.6\ in^2 \times \frac{2.54^2\ cm^2}{1\ in^2} = 314\ cm^2$$

(e) Convert 55.0 m^3 to $feet^3$ (ft^3). 1 ft = 12 in. (*Ans*. $1.94 \times 10^3\ ft^3$)

When converting ratios, for example miles per gallon (mpg) to kilometres per litre, convert the two units separately and then divide.

(f) Convert 35.0 mpg to km/L. (*Ans*. 12.4 km/L)
(g) Convert 11.5 L/100 km to mpg. (*Ans*. 24.6 mpg)
(h) Convert 38.5 mpg to L/100 km. (*Ans*. 7.34 L/100 km)
(i) The directions on a 1 gallon (4.55 L) can of paint says that 1 gallon will cover 100. ft^2. How many litres will be needed to paint an area of 45.0 m^2? (*Ans*.22.0 L)

7. **Density**

For any substance, the mass and volume depend on the size of the sample. For a pure substance at a constant temperature, $\frac{\text{mass}}{\text{volume}}$ = constant = density (D).

In most cases, use mass in grams.
For solids, V in cm^3, hence D in g/cm^3 ($\approx$ 0.5 - 30 g/cm^3)
For liquids, V in mL, hence D in g/mL ($\approx$ 0.5 - 15 g/mL)
For gases, V in L, hence D in g/L ($\approx$ 0.1 - 16 g/L)

$$D = \frac{M}{V} \quad M = DV\ (g = g/mL \times mL) \quad V = \frac{M}{D}\ (mL = g \div g/mL = g \times mL/g)$$

(a) For carbon tetrachloride, 25.0 mL have a mass of 39.75 g. Calculate its density. (*Ans*. 1.59 g/mL)

(b) The density of mercury is 13.6 g/mL. What is the volume of 55.0 g of mercury? (*Ans*. 4.04 mL)

(c) What is the mass of 15.0 mL of mercury? (*Ans*. 204 g)

(d) The mass of an empty 50.0 mL flask is 18.1078 g. The flask was filled with alcohol and the mass of the flask plus alcohol was found to be 57.5574 g. Calculate the density of alcohol. (*Ans*. 0.789 g/mL)

(e) The mass of an empty flask is 15.2568 g. When the flask was filled with alcohol, the mass of the flask plus alcohol was found to be 46.8171 g. Calculate the volume of the flask. (*Ans*. 40.0 mL)

(f) The mass of an empty flask was found to be 20.2575 g. When filled with alcohol, the mass of flask plus alcohol was 41.7218 g. When filled with liquid A of unknown density, the mass of flask plus liquid A was 48.7827 g. Calculate the density of liquid A. (*Ans*. 1.05 g/mL)

(g) Calculate the density of solid B of unknown density from the following data. A 25.00 mL flask weighed 11.2519 g. Several pieces of solid B were placed in the flask and the mass of flask plus solid B was found to be 18.1706 g. Alcohol was then added to fill the flask and the mass of flask, solid B and alcohol was found to be 33.7218 g. (Solid B does not dissolve in alcohol nor does it absorb alcohol). (*Ans*. 1.31 g/cm^3)

8. **Temperature**

$$°F = (1.8 \times °C) + 32 \qquad °C = \frac{°F - 32}{1.8} \qquad K = °C + 273.15$$

(a) Convert 45°C to °F. (*Ans*. 113°F)

(b) Convert 128°F to °C. (*Ans*. 53.3°C)

(c) Convert 185 K to °C. (*Ans*. -88°C)

(d) Convert -40°C to °F. (*Ans*. -40°F)

(e) Convert 14°F to °C. (*Ans*. -10°C)

9. **Energy Change: Heat Flow** (Section 3.6)
Heat is one form of energy. When a substance is heated, it gains energy and the temperature increases; when it cools it loses energy and the temperature decreases. Thus heat flow indicates a change in energy.

1 calorie [1 cal = 4.184 J (joules)] is the amount of energy needed to raise the temperature of 1 g of water by 1°C.

In addition to temperature change, the amount of energy gained or lost by a substance also depends on the mass of the substance and the identity of the substance. Note that 1 cal = amount of heat to

raise the temperature of	1 g	of	water	by	1°C
heat flow depends on	**mass**		**substance**		**temperature change**

The property of a substance that measures how much heat energy is lost or gained when the temperature of 1 g of the substance changes by 1°C is called its *specific heat* (*s*).
Let change in energy = Q, mass = m and change in temperature = ΔT.
$Q = s \times m \times \Delta T$ (Note that ΔT in °C or K has the same value)

From the definition of a calorie (N.B.: the calorie used for foods is usually written Calorie and is really a kilocalorie), it follows that the specific heat of water is 1 cal/g·°C or 4.184 J/g·°C. The values of the specific heats of some other substances are given in Table 3.2.

(a) How much energy is needed to raise the temperature of 15.0 g of aluminum from 25.0°C to 32.0°C? For aluminum, s = 0.89 J/g·°C. (*Ans*. 93 J)

(b) When 454 g of nickel at 55.6°C loses 6.93 kJ, the temperature falls to 21.2°C. Calculate the specific heat of nickel in J/g·°C. (*Ans*. 0.444 J/g·°C)

(c) When a 13.6 g piece of aluminum gains 309 J, the temperature rises to 42.3°C. Calculate the initial temperature of the aluminum. (N.B.: solve for ΔT first) (*Ans*. 17°C)

(d) A 57.5 g sample of nickel at 28.6°C loses 873 J. Calculate the final temperature of the nickel. (*Ans*. -5.6°C)

(e) When a 273 g piece of iron (d = 7.87 g/cm^3) at 47.1°C was added to 50.0 mL of water in an insulated container at 22.0°C, the final temperature of the iron and water became 31.3°C. Calculate the specific heat of the iron. Assume that all of the heat lost by the iron is gained by the water. (*Ans*. 0.45 J/g·°C)

(f) A bar of silver at 68.5°F gains 1.50 kcal of heat and the temperature rises to 79.8°F. What is the mass of the bar in kilograms? For silver, s = 0.24 J/g·°C. (*Ans*. 4.2 kg)

(g) A 92.0 g piece of iron (s = 0.45 J/g·°C) at 72.3°C was added to 25.0 mL of water in an insulated container at 18.5°C. After a few minutes, the iron and water attained the same temperature. Calculate this temperature. Assume that all of the heat lost by the iron is gained by the water. (*Ans*. 34°C)

Additional Conversion Problems

1. Convert 75.5 cm to nm. (*Ans*. 7.55 x 10^8 nm)

2. Convert 24 knots to cm/s. 1 knot is a unit of speed used by boats is 1.1508 miles per hour; 1 in = 2.54 cm; 12 in = 1 ft; 5280 ft = 1 mile. (*Ans*. 1.2 x 10^3 cm/s)

3. How many metres tall is a horse that stands 15 hands? 1 hand = 4.00 in; 1 in = 2.54 cm) (*Ans*. 1.5 m)

4. Convert a density of 6.54 g/cm^3 to tons/yd^3. 1 yd = 3 ft; 1 ft = 12 in; 1 in = 2.54 cm; 454 g = 1 lb; 2000 lb = 1 ton. (*Ans*. 5.51 tons/yd^3)

Additional Volume Problems

1. Calculate the volume of a rectangular solid of length 8.5 cm, width 2.7 cm and thickness 6.5 mm. (*Ans*. 15 cm^3)

2. A thin rectangular solid is 355 cm long and 48 cm wide and has a volume of 3.75 cm^3. Calculate the thickness of the solid. (*Ans.* 2.2 x 10^{-4} cm)

3. Calculate the radius of a 33 cm long cylinder whose volume is 66 cm^3. (*Ans*. 8.0 mm)

4. Calculate the radius of a sphere whose volume is 258 in^3. (*Ans.* 3.95 in)