Chapter 5 – Scientific Measurement

1) The Importance of Measurement
   a) Qualitative Measurements give results in a descriptive, non-numeric form.
   b) Quantitative Measurements give results in definite form, usually as numbers.

   Example – Classify as qualitative or quantitative
   1. By feeling your forehead, you say you have a fever.
   2. By using a thermometer, your temperature is measured as 102.5°F.

2) Sec 5.1 and Appendix C – Scientific Notation and Use of the Calculator
   Very large and very small numbers are easier to work with when they are put into exponential form. A number is in scientific notation when it is written as $A \times 10^n$, where $1 \leq A < 10$ and n is an integer. $602{,}000{,}000{,}000{,}000{,}000{,}000{,}000 = 6.02 \times 10^{23}$

   Note: $10^0 = 1$, $10^1 = 10$, $10^2 = 100$, $10^{-1} = 0.1$, $10^{-2} = 0.01$

   Examples
   1. Write the following numbers in scientific notation:
      a) 5450 = b) 0.0000786 =
   2. Write the following numbers as regular numbers:
      a) $5.68 \times 10^5 =$ b) $3.46 \times 10^{-5} =$
   3. Perform the following calculations using a calculator:
      a) $\dfrac{456 \times 743}{254 \times 758} =$ b) $\dfrac{45.6 + 23.4}{2.68} =$ c) $\dfrac{1.8 \times 2.65}{454 - 23.8} =$

      d) $5.64 \times 10^5 + 3.85 \times 10^6 =$ e) $\dfrac{(6.8 \times 10^{-5}) \times (7.5 \times 10^8)}{6.25 \times 10^{-3}} =$

      f) $\dfrac{(3.6 \times 10^{-3})^2 \times \sqrt{2.5 \times 10^6}}{6.35 \times 10^8 + 3.75 \times 10^7} =$ g) $(3.56 \times 10^{-4})^5 \times \sqrt[7]{7.35 \times 10^9} =$

3) Sec 5.2 - The International System of Units, SI (Metric System)
   The English system used in daily activities presents some problems in scientific use. In a sense, it is a system that just grew. The units have practical size for common use. However, the chief disadvantage of the English system is that no single, simple numerical relationship exits between different units of measure. For example, 12 inches = 1 foot, 3 feet = 1 yard, 5280 feet = 1760 yards = 1 mile.

   The Metric system, developed in France near the end of the 18th century, is used in scientific work throughout the world. It is in general use in practically all countries except the United States. Many American industries that participate in foreign markets have adopted the metric system. By the Metric Conversion Act of 1975, the United States was formally committed to encourage, but not to require, the change to metric measurements.

   The metric system is a decimal system that has a single, simple numerical relationship between units. Computations with measurements are easily performed. A standard set of prefixes is used to expand the basic metric system. A revised version, the International System of Units (SI) was adopted by international agreement in 1960. The SI system has seven basic units from which other SI units of measurement such as volume, density, and pressure are derived. Although it is possible to report all measurements in SI units, we will not do so in this class.

Metric System Prefixes – In this class we will use the following prefixes:

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) = 10^{-6} nano (n) = 10^{-9}

4) Sec 5.3 – Units of Length – The meter (m) is the basic unit of length
1 m = 39.4 in, 1 in = 2.54 cm, 1 mile = 1.61 km

Examples: What metric unit of length would be the best to describe the following?
a) The length of you foot
b) The distance between Saint Louis and Chicago
c) The diameter of a bolt

5) Sec 2.8 – Units of Volume – The space occupied by matter is called volume. It is a derived unit. Volume is calculated from linear measurements of length, width, and height. The SI unit of volume is the cubic meter (m^3). A more convenient metric unit is the liter (L). A liter is the volume of a cube that is 10 cm on each edge. There are 1000 liters in a cubic meter. (1 m^3 = 1000 L)

1 L = 1000 cm^3 (cc) and 1 mL = 1 cc 1 L = 1.06 qt, 1 qt = 946 mL

Examples: What metric unit of volume would be used for the following?
1) A tankful of gasoline
2. Amount of milk added to a recipe

6) Units of Mass
a) Mass is a measure of the total quantity of matter in an object. Weight is a measure of the force exerted on an object by the pull of gravity. The mass of an object is always the same, but the weight of an object is a variable depending upon the geographical location of the object.

b) The mass of an object is measured by comparing it to a standard mass of 1 Kg, which is the basic SI unit of mass. A kilogram is the mass of 1 L of water at 4°C.
1 kg = 2.2 lbs, 1 lb = 454 g, 1 oz = 28.4 g

Examples: What metric unit of mass would be used for the following?
1. Your mass
2. The mass of a penny

7) Sec 5.4 – Uncertainty: Accuracy and Precision
a) Accuracy is how close a measurement comes to the actual dimension or true value of whatever is measured.
b) Precision is concerned with the reproducibility of whatever is measured. It is how close

together separate measurements are to each other.

Example – Comment on the accuracy and precision of the following experimental results for three different trials each. The accepted value is 22.4.

1. Abbey obtained results of 18.6, 19.0, and 18.9.
2. Nikki obtained results of 18.6, 20.6, and 28.0.
3. Julie obtained results of 22.2, 22.3, and 22.6.

8) Sec 5.5 – Significant Figures in Measurements

a) We often make measurements that we then use to calculate other values. The value obtained in the calculation is obviously related to the accuracy of the measurements, but it is also related to how much we "round off" our calculations.

Example – Divide 365 by 2240. Then multiply the answer by 215. What value do you get if you round the quotient to:
1. one place past the decimal point before multiplying by 215 Ans. =
2. two places past the decimal point before multiplying by 215 Ans. =
3. three places past the decimal point before multiplying by 215 Ans. =

b) The accuracy of any measurement depends upon the instrument used and upon the observer. The data that should be recorded consist of the definitely known digits plus one estimated digit. The digits that are known plus the first digit that is uncertain are known as the significant digits or significant figures.

c) Not all the numbers we use come from measurements. Sometimes we use numbers that come from a direct count of objects or that come from definitions. Such numbers are called exact numbers and have an infinite number of significant figures.

d) In a recorded measurement, we will assume the following:

1. All non-zero digits are significant.
2. "Imbedded" zeros are significant (zeros between other digits).
3. Zeros at the end of a number and to the right of the decimal point are significant.
4. Zeros used to place the decimal
   a. are not significant if they are "leading" zeros (zeros to the right of the decimal with no non-zero digits in front.)
   b. may or may not be significant if they are "trailing" zeros (zeros to the right of non-zero digits but to the left of the decimal point).

Example How many significant digits are in the following measurements?

1. 3658 m 2. 0.0260 L 3. 1.206 4. 0.0003 Km 5. 12 people

9) Significant Figures in Calculations

a) Most calculations involve numbers measured by someone. Calculations should indicate only the degree of accuracy justified, never a higher accuracy, never the limit of the calculator. An answer cannot be more precise than the least precise measurement.

b) Rounding Off Rule – If the digit following the last significant digit is less than 5, all the digits after the last significant digit are dropped. If the digit is 5 or greater, the value of the digit in the last significant place is increased by 1.
Example – Round off each measurement to three significant figures.

1. 87.073 =   2. 4.3621×10^8 =   3. 0.01552 =

c) In addition or subtraction, the sum or difference cannot be stated to more places after the decimal point than the number with the least number of places after the decimal point.
Examples

1. 15.7 + 6.40 + 14.8968 =   2. 150.00 - 2.1 + 1.030 =

d) In multiplication or division, the answer should contain the same number of significant digits as the least accurate measurement.
Examples

1. 2.38 x 2.1 =   2. $\frac{2.460 \times 25.6}{0.0064}$ =

10) Sec 5.6 – A Technique of Problem Solving – Dimensional Analysis
In dimensional analysis we use the units (dimensions) that are part of measurements to help solve (analyze) the problem.

Units cancel just as numbers do. If you cancel the units FIRST, then the numbers will have to give you the correct answer.

Steps
a) Identify the unknown as well as the units of the quantity to be determined.

b) Identify what is Known or Given (both a numerical value and its units).

c) Plan a solution. You will need conversion factors that will get you from the given units to the unknown's units. Obtain these conversion factors from the list that is available to you.

d) Multiply by the conversion factors in a manner such that the unwanted (original) units are cancelled out, leaving only the desired units.

e) Do the calculations as indicated by the conversion factors.

f) Finish up. The answer should always be expressed to the correct number of significant figures. Also, check your work. Does your answer make sense?

11) Conversion Factors – In a conversion factor, the measurement in the numerator is equivalent to the measurement in the denominator. When a measurement is multiplied by a conversion factor, the value of the measurement remains the same. Although the numerical value of the measurement is changed, the change in the units compensates for

this. Many conversion factors are defined quantities and thus have an unlimited number of significant figures.

Note: a x 1 = a; 1 ft = 12 in so $\frac{1\ \text{ft}}{12\ \text{in}} = 1$ and $\frac{12\ \text{in}}{1\ \text{ft}} = 1$

12) Converting Between Units – Examples

a) 500 g = Kg

b) 250 cc = L

c) 53.5 cm = Km

d) 4.65 Kcal/min = cal/sec

e) How large a container, in liters, would you need to hold 10.0 Kg of alcohol? (Assume a density of 0.790 g/cc for alcohol.)

13) Multi-Step Problems and Converting Complex Units – Examples

a) 100 yards = meters

b) An automobile can get 15 Km per liter. What is this in miles per gallon?

c) How many square meters are there in a lot that is 80 feet by 120 feet?

d) How many pounds of water can be held by a cylindrical tank with a radius of 2 feet and a height of 6 feet? (Assume the density of water is 1.0 g/mL.)

14) Sec 5.7 – Measuring Temperature – Temperature is a measure of the hotness or coldness of an object. Almost all substances expand with an increase in temperature and contract as the temperature decreases. This property is the basis for most common thermometers. Thermometers will give temperatures in one of two scales: the Celsius scale or the Fahrenheit scale. A third temperature scale that we will use in calculations is the Kelvin or absolute scale. Within thermometers the fluids expand linearly by the same amount no matter what the temperature is.

0°K (-273°C, -459°F) is the predicted lowest temperature possible. For calculations, there can be no negative temperatures.

Boiling point of water ---- 100 ---- 212 °F = 1.8 °C + 32
| |
Freezing point of water — 0 ---- 32 °K = °C + 273

Examples:

1. What is normal body temperature in °C and °K?

2. What is the temperature outside if your thermometer reads -15°C?

15) Sec 5.8 – Density is the ratio of the mass of an object to its volume.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$ units are g/mL or g/cc

Densities of some common substances at 25°C (in g/cc)

Au = 19.3, Hg = 13.6, Pb = 11.3, Al = 2.70, H_2O = 0.997, ethanol = 0.789

Sample Calculations

1. A stone removed from the gall bladder of a patient has a volume of 2.2 cc and a mass of 1.89 g. What is its density? Will it float in water?

2. When 49.33 g of lead were placed in a graduated cylinder containing 15.0 mL of water, the water level increased to 19.4 mL. What is the density of the lead?

3. Calculate the density of a piece of metal that has a mass of 38.4 g and is 5.2 cm long, 2.3 cm wide, and 1.1 cm high.

16) Evaluating Measurements

a) Error = |Accepted Value - Experimental Value| (always positive)

b) Percentage Error = $\frac{|\text{Error}|}{\text{Accepted Value}} \times 100$

Examples: What is the error and percentage error in each of the following?

a) A student sold $10 worth of candy, but only collected $6.

b) A clerk sold $10,000 worth of goods, but collected only $9996.