Chapter 2
Measures & Calculations

Scientific Method

I. Approach
- A. Observing
  - 1. Use of 5 senses
  - 2. Use of instrumentation
  - 3. System – selected region of focus for experimentation
  - 4. Formulate hypothesis – testable statement attempting to explain observations
- B. Researching current knowledge about chosen system/ proposed hypothesis
  - 1. Publications
  - 2. Presentations/ conferences
- C. Experimentation
  - 1. Controls – experimental conditions that remain constant
  - 2. Variable – any condition that changes
    - a. Independent variable (I.V.)– The condition/factor being tested for an effect
    - b. Dependent variable – Condition/ factor being measured as a result of I.V.
- D. Theorizing
  - 1. Formulated upon successful outcome of predictions
    - a. Basis for constructing a model (visual, verbal, &/or mathematical)
  - 2. Broad generalization seeking to explain a body of facts/ phenomena
    - a. Strong predictive powers
    - b. Sweeping applications

Measurements

I. Types
- A. Qualitative
  - 1. Descriptive, non-numerical
  - 2. Subjective - does not have consensus
- B. Quantitative
  - 1. Definite form, usually numerical
  - 2. Can be compared with others' data
  - 3. Only as reliable as the instrument of measurement

II. Expression
- A. Scientific Notation
  - 1. Written as product of a coefficient and an exponent of 10 (10 raised to a power)
    - a. Coefficient is a real number, ≥ 1 and < 10

      $7.25 \times 10^5 = 725{,}000$

      $6.1462 \times 10^{-2} = 6.1462 \times 1/100 = 6.1462 \div 100 = 0.061462$

      $1.43 \times 10^0 = 1.43 \times 1 = 1.43$
    - b. The exponent is also a whole number, negative to positive infinity
      - (+) indicates the number of times the coefficient must be multiplied by 10
      - (-) indicates the number of times the coefficient must be divided by 10
  - 2. Mathematical manipulation
    - a. Multiplication: multiply coefficients and add exponents

      $[2.54 \times 10^6] \times [2.1 \times 10^{-4}] = (2.54 \times 2.1)(10^{6+(-4)}) = 5.334 \times 10^2$
    - b. Division: divide the coefficients and then subtract the denominator's exponent from the exponent of the numerator

      $[2.54 \times 10^6] / [2.1 \times 10^{-4}] = (2.54 / 2.1)(10^{6-(-4)}) = 5.334 \times 10^{10}$
    - c. Addition or subtraction: make the exponents the same power

      $[5.4 \times 10^3] + [6.0 \times 10^2] = [5.4 \times 10^3] + [0.6 \times 10^3] = [5.4 + 0.6] \times 10^3$

      $[5.4 \times 10^3] - [6.0 \times 10^2] = [5.4 \times 10^3] - [0.6 \times 10^3] = [5.4 - 0.6] \times 10^3$

III. Uncertainty in measurement
- A. Accuracy
  - 1. Measure how close a measurement comes to the actual or true value

2. The goal is to approach/ reach the "accepted value", i.e. what is considered right

B. Precision

1. Measure how close a series of measurements are to one another
2. Is a function of reproducibility

C. Error

1. The difference b/w the accepted value & the experimental (lab) value
2. Error = experimental value - accepted value
3. Percent error ={absolute value of error divided by the accepted value} x 100%
    - a. Calculate the % Error for the boiling point measurement of water

      % Error = $[(99.1\ ^{O}C - 100.0\ ^{O}C) / 100.0\ ^{O}C] \times 100\ \%$
    - b. Positive % error if the accepted value is < lab value; neg % if > lab value

D. Significant Figures

1. Includes all the digits in a number that are known, **plus** a last digit that is estimated
    - a. Every non-zero digit is assumed to be significant.

      24.7 m or 0.775 or 648 all have <u>**3**</u> significant figures
    - b. Every zero found between other significant figures is also significant

      36005 cm or 3.022 ml or 3000.8 have <u>**4**</u> significant figures
    - c. Left-most zeroes appearing in front of significant figures are **not** significant.

      These act merely as placeholders, as illustrated with scientific notation.

      0.00048 or 0.36 or 4.7 or 0.00000000015 have <u>**2**</u> significant figures

      4.8×10^{-4} or 3.6×10^{-1} or 4.7×10^{0} or 1.5×10^{-10}
    - d. Right-most 0's left of the decimal point are not significant if they're placeholders

      3000 m or 7000 ml or 0.4 g has only <u>**1**</u> significant figure
    - e. Zeroes at the end of a number & to the right of a decimal point are always significant.

      43.00, 1.010, & 9.000 have <u>**4**</u> significant figures.
    - f. Counted items & exactly defined quantities have unlimited number of sig figures.

      23 people, 60 seconds = 1 minute
2. Rounding In Calculations
    - *a. Multiplication & dividing*
        - Round to the least significant figure of the numbers being used

          (5.4)(7.7)= 41.58 BUT ONLY HAS 2 S.F., so can only say is 42!
        - If the digit to the right of the last significant digit is <5, drop it

          Round 56.312 to 4 S.F. = 56.31
        - If the digit to the right of the last significant digit is $\geq$ 5, round up 1

          Round 56.315 to 4 S.F. = 56.32
    - *b. Addition & subtraction*
        - Round to the <u>same # of decimal places</u> as the # with least # of decimal places

          (NOTE: # decimal places is NOT EQUAL to # digits)

      12.<u>52</u> + 349.<u>0</u> + 8.<u>24</u> = 369.76, but 349.<u>0</u> has only 1 decimal place, so= 3.698×10^{2}

V. International System of Units (SI)

A. Base Units

- a. Meter (m) - length
- b. Kilogram (kg) - mass
- c. Kelvin (K) - temperature
- d. Second (s) - time
- e. Mole (m) - amount of substance
- f. Candela (cd) - luminous intensity
- g. Ampere (A) - electric current

B. Derived Units

- a. Cubic meter (m^3) - volume
- b. Grams per cubic centimeter (g/cm^3) or grams per milliliter (g/ml) - density
- c. Pascal (Pa) - pressure
- d. Joule (J) – energy – force x length = Newton meter (Nm)
- e. Molar mass (M) – amount in grams/mole

C. Non-SI units

1. Liter (L) - volume = vol. of cube 10 cm along each edge = $(10\ cm)^3 = 1000\ cm^3$ = 1000 ml

2. Degrees Celsius (ºC) - temperature
3. Atmosphere (atm) - pressure
4. Millimeters of Mercury (mm Hg) - pressure
5. Calorie (cal) - energy

D. Commonly used prefixes in the metric system
1. T – tera – 10^{12} = 1,000,000,000,000
2. G – giga – 10^{9} = 1,000,000,000
3. M - mega - 10^{6} = 1,000,000
4. k - kilo - 10^{3} = 1,000
5. h – hecto – 10^{2} = 100
6. dk - deca - 10^{1} = 10
7. d - deci - 10^{-1} = 1/10
8. c - centi - 10^{-2} = 1/100
9. m - milli - 10^{-3} = 1/1000
10. μ - micro - 10^{-6} = 1/1,000,000
11. n - nano - 10^{-9} = 1/1,000,000,000
12. p - pico - 10^{-12} = 1/1,000,000,000,000
13. f – femto – 10^{-15} = 1/ 1,000,000,000,000,000

E. Units of volume
1. The space occupied by any sample of matter
   a. Liter is common unit of volume
   b. Volumes will change with temperature; use 25 ºC as standard temperature

F. Units of Mass
1. Mass ≡ a measure of the quantity of matter
   a. The kilogram (kg) is standard mass
   b. A kg was originally defined as the mass of 1 L of H_2O @ 4 ºC
   c. A gram (g) is 1/1000 of a kilogram
2. Weight ≡ a force that measures the pull on a given mass by gravity

VI. Density

A. Density
1. Density is the ratio of the mass of an object to its volume
2. Density = mass / volume; typically, d = g/cm^3

B. Specific Gravity
1. Comparison of the density of a substance with the density of a reference substance
   a. Comparisons are usually at the same temperature
   b. Specific density = $\frac{\text{density of X } (g/cm^3)}{\text{density of } H_2O\ (g/cm^3)}$
   c. Note that the units cancel out, so specific gravity has no units
2. Measured
   a. Hydrometer is device used to measure specific gravity
   b. Common uses
      Urine is checked in diagnosing diabetes
      Radiator fluid is checked to determine % antifreeze
      Car batteries are checked to determine % acid

VII. Conversion Factors

A. Allows conversion from 1 unit to another
B. Relies on equality between 2 different units; e.g. 4 quarters= 1 dollar = 10 dimes
C. Dimensional analysis
   1. quantity sought = quantity given x conversion factor
   2. In conversion factors, have your desired outcome in the numerator if multiplied & in the denominator if you are dividing it into another number
   e. ºC + 273.15 = K [Note the lack of a degree symbol.]

VIII. Temperature

A. Measuring
1. Temperature determines the direction of heat transfer
2. Heat moves from the area of greater temperature to area of lower temperature

3. Almost all substances expand with an increase in temperature & contract with a decrease
    a. Water is the exception
    b. Mercury in thermometers expands with increased temperatures
    c. Bilayer metals in thermostats respond with expansion to different degrees

B. Scales
1. Celsius
    a. Named after Swedish astronomer Anders Celsius
    b. Based on 2 reference points: Freezing (0 ^oC) & Boiling (100 ^oC) Points of pure water
    c. The difference between B.P. & F.P. was divided equally into 100 intervals
2. Kelvin
    a. Named after Scottish physicist & mathematician Lord Kelvin
    b. Also called the absolute scale
    c. Freezing point of water is set at 273.15 K & boiling point at 373.15 K
    d. Absolute zero Kelvin, 0 K, equals -273.15 ^oC

IX. Proportionality

A. Directly proportional
1. $y \alpha x$ or $y/x = k$ or $y = k x$
2. Graphing *x* versus *y* will give you a straight line with a positive slope passing thru the origin

B. Inversely proportional
1. $y \alpha 1/x$ or $x y = k$
2. Graphing *x* versus *y* will give you a hyperbola curve