IMPORTANT CHEMICAL CONCEPTS:

SOLUTIONS, CONCENTRATIONS, STOICHIOMETRY

I. Introduction

A. Course outline will be reviewed.

B. Laboratory experiments will be discussed in class.

II. Units of Measurement.

A. S.I. (Systeme International d'Units).

1. The S.I. units consist of a minimum number of fundamental units, which do not depend on position (or gravity). Unit system of units that does this is called a set of "absolute" units.

2. S.I. Base (Fundamental) Units:

Physical Property	***Unit (mks)***
Mass	kilogram (kg)
Length	meter (m)
Time	second (s)
Temperature	Kelvin (K)
Amount of Substance	mole (mol)
Electrical current	Ampere (A)
Luminous intensity	Candela (cd)

3. S.I. unit size can be changed at will by using metric prefixes:

Prefix	***Abbreviation***	***Multiplier***
exa-	E	10^{+18}
peta-	P	10^{+15}
tera-	T	10^{+12}
giga-	G	10^{+9}
mega-	M	10^{+6}
kilo-	k	10^{+3}
deca-	da	10^{+1}
deci-	d	10^{-1}
centi-	c	10^{-2}
milli-	m	10^{-3}
micro-	□	10^{-6}
nano-	n	10^{-9}
pico-	p	10^{-12}
femto-	f	10^{-15}
atto-	a	10^{-18}

B. S.I. unit for chemical quantity: the mole

1. The mole is also called Avogadro's number: $6.022 \times 10^{+23}$.
2. A mole is defined as the number of carbon atoms in exactly 12.00 grams of carbon-12.
3. The definition is selected so that the formula weight (in amu) and the molar mass (in grams/mol) have the same *numerical* value.
4. For example: consider water, H_2O

<u>*Formula Weight:*</u>
2 atoms H(1.0 amu/atom) = 2.0 amu
1 atom O(16.0 amu/atom) = 16.0 amu
Formula Weight = 18.0 amu/formula

Molar Mass = 18.0 grams/mol

III. Units of Concentration

Concentration is expressed in a variety of ways.

A. The most general definition:

concentration = amount of solute/amount of solution

B. Common units used by chemists include:

1. Molarity (M) = # moles solute/#liters of solution

2. Formality (F) = #moles solute/#liters of solution

Usually used to express the concentration of the strong electrolytes and emphasize that a substance is converted into other species in the solution.

3. Normality (N) = #equivalents solute/#liters of solution.

Normality must be specified with respect to a definite reaction.

a. For acid-base reactions, 1 equivalent = 1 mole of hydrogen ions (or 1 mole of hydroxide ion) donated.

b. For oxidation-reduction reactions, 1 equivalent = 1 mole of electrons.

c. For determining electrolyte concentration, 1 equivalent = 1 mole of charge.

Normality = (Molarity)(#electrons transferred), or
= (Molarity)(#hydrogen ions neutralized)
= (Molarity)(#hydroxide ions neutralized)

For example: $MnO_4^- + 8H^+ + 5e^- \Leftrightarrow Mn^{2+} + 4H_2O$

The normality of permanganate ion is five times its molarity, because MnO_4^- ion accepts 5 electrons. So, the molarity of permanganate is 0.1 M, the normality for the reaction

$$MnO_4^- + 5Fe^{2+} + 8H^+ \Leftrightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$$

is 0.1 x 5 = 0.5 N. Five electrons are coming from five Fe^{2+} ions.

Analogously, for the following reaction MnO_4^- accepts 3 electrons

$$MnO_4^- + 4H^+ + 3e^- \Leftrightarrow MnO_2 + 2H_2O$$

If normality of the permanganate is 0.06N, then molarity of the MnO_4^- is 0.02 M.

The normality of a solution is a statement of the moles of "reacting units" per liter. One mole of "reacting units" is called equivalent. Therefore, equiv/L are units for Normality.

The equivalents = weight/equivalent weight. [The equivalent weight equals the formula weight divided by the number of electrons transferred or the number of hydrogen ions (hydroxide ions) neutralized (i.e., it is the weight that corresponds to one equivalent).]

4. Molality (m) = #moles of solute/#kilograms of solvent

5. Osmolarity (O or osM) = #total moles of particles/#liters of solution

6. Parts per thousand:

C_{ppt} = [weight of substance/weight of solution] x 1,000 ppt

7. Parts per million:

C_{ppm} = [weight of substance/weight of solution] x 10^{+6} ppm

Note that for dilute, aqueous solutions, 1 ppm = 1 mg/L because 1 L approximately equals 1 kilogram of solution.

C_{ppm} = [weight of substance(mg)/volume of solution(L)] x10^{+6} ppm

8. Percent concentration (or parts per hundred) can be expressed several ways:

a. Weight percent (w/w):

$C_{(w/w)}$ = [weight solute/weight solution]x100%

b. Volume percent (v/v):

$C_{(v/v)}$ = [volume solute/volume solution]x100%

c. Weight/Volume percent (w/v):

$C_{(w/v)}$ = [weight solute(g)/volume solution(mL)]x100%

d. Usage of percent concentration varies. For example, commercial aqueous reagents are usually sold in a weight % (w/w):

1. 37% HCl means 37 g HCl/100 g solution.

2. To calculate the molarity of the HCl requires knowledge of the density of the solution:

Example: Find molarity of the 37 wt % HCl. Density of the solution is 1.19g/ml.

Step 1. Mass of HCl per liter of the solution:

$$(1.19 \cdot 10^{3}\, g\, solution/L)(0.37\, g\, HCl\, /\, g\, solution) = 4.40 \cdot 10^{2}\, g\, HCl\, /\, L$$

MW of the HCl is 36.46 g/mol

Step 2. Molarity of the solution is:

$$\frac{4.40 \cdot 10^{2}\, g\, HCl\, /\, L}{3646\, g\, HCl\, /\, mol} = 121\, mol/L = 121\, M$$

IV. Confusion Over Concentration Units

A. Confusion of the different types of percent concentration can cause significant errors. For example: Compare 5% (w/v) ethanol to 5% (v/v) ethanol

5% (w/v) ==> [5.00 g/100 mL]x100%

5.00 g (1 mol/46.0 g) = 0.109 mol ethanol/100 mL

5% (v/v) ==> [5.00 mL/100 mL]x100%

5.00 mL(0.7893 g/mL)(1 mol/46.0 g) = 0.0859 mol/100 mL

There is a 21.2% difference in these two concentration!!!

B. Confusion of Molarity and Formality (Analytical Molarity).

1. For example, what is the concentration of a solution prepared by dissolving exactly 1 mol of acetic acid in 1 liter of solution (both M and F)?

$$HC_2H_3O_2 + H_2O \Leftrightarrow H_3O^+ + C_2H_3O_2^-$$

$K_a = [H^+][C_2H_3O_2^-]/[HC_2H_3O_2] = 1.79 \times 10^{-5}$

Note that $[H^+] = [C_2H_3O_2^-]$ if you ignore the water contribution to the hydrogen ion concentration.

Thus,

$K_a = [X][X]/[1 - X] = X^2/[1 - X] = 1.79 \times 10^{-5}$

Solving for X,

$X^2 = 1.79 \times 10^{-5} - (1.79 \times 10^{-5})X$

$X^2 + (1.79 \times 10^{-5})X = 1.79 \times 10^{-5}$

Ignoring the "$(1.79 \times 10^{-5})X$" term,

$X = \sqrt{1.79 \cdot 10^{-5}} = 0.00423\ [H^+] = 0.00423\ [C_2H_3O_2^-]$

$1 - X = 1 - 0.00423 = 0.99577$ mol $HC_2H_3O_2$ left unionized

$M_{acetic\ acid} = 0.99577$ (or 0.423% has ionized)

$F_{acetic\ acid} = 1.00000$

Note that the pH of the solution is...

$pH = -\log_{10}([H^+]) = -\log_{10}(0.00423)$

$pH = 2.37$

V. p-Functions

A. p-Functions are a method of expressing concentrations, especially very large or very small values.

B. pH is the most commonly known p-function:

$pH = -\log_{10}([H^+])$

C. The p-function ($pX = -\log_{10}([X])$) can be applied to any molar concentration of any species.

1. For example, what is the p[OH] of a 0.1 F NaOH solution?

$NaOH \rightarrow Na^+ + OH^-$

$[OH^{1-}] = 0.1\ M \Rightarrow p[OH] = -\log_{10}([0.1]) = 1$

(Note that the pH = 13, since it is ***always*** true that pH + pOH = 14.)

VI. Density and Specific Gravity

A. Density = mass/volume

1. The units are usually grams/mL.

B. Specific Gravity = (Density of substance)/(Density of water at 4^0C)

1. Note that the temperature must be specified for specific gravity.

2. Specific gravity is a unitless ratio (i.e., it doesn't matter what the units are so long the same

units are used for the substance and water).

3. Specific gravity is more often used in commerce and commercial reagent labeling than density.

VII. Stoichiometric Calculations and the Factor-Label Method (Dimensional Analysis)

A. Steps in the method:

1. Write a balanced equation for the reaction.

2. Compute (or look up) all molar masses.

3. Write down the given and unknown quantities.

4. Setup conversion factors (A conversion factor is an expression for the relationship between quantities, or units) using the stoichiometric coefficients in the balanced equation.

For example, suppose 4.0 g of hydrogen gas reacts with excess oxygen gas to produce water. How many grams of oxygen are required, and how many grams of water can be made?

Write the equation and balance it:

$$2H_2 + O_2 \Rightarrow 2H_2O$$

Step 1. Show what (quantities and units) you are given on the left, and what (quantities and units) you want on the right.

4.0 g H_2 = ? g O_2

Step 2. Insert the required conversion factors to change between quantities and units.

4.0 g H_2(1 mol H_2/2.0 g H_2)(1 mol O_2/2 mol H_2)(32.0 g O_2/1 mol O_2) = ? g O_2

Step 3. Cancel units where you can, and solve the math.

4.0 g H_2(1 mol H_2/2.0 g H_2)(1 mol O_2/2 mol H_2)(32.0 g O_2/1 mol O_2) = 32 g O_2

Analogously, to calculate the g H_2O:

4.0 g H_2(1 mol H_2/2.0 g H_2)(2 mol H_2O/2 mol H_2)(18.0 g H_2O/1 mol H_2O) = 36 g H_2O

5. Always check your calculations to see that:
   a. The units cancel to get the desired unit.
   b. The grams of reactants = grams of product.