CHEMISTRY 109 – Help Sheet #6
REVIEW (Part VI): Stoichiometry (Part III)

***** Review the appropriate topics for your lecture*****

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https://clc.chem.wisc.edu (Resources page)

Nuggets: *Molarity, Dilutions, Stoichiometry with M (Titrations)*

MOLARITY – concentration of solutions

abbreviated as M (pronounced "molar"); square brackets, $[X^+]$, means the concentration of X^+ in molarity

$$\mathbf{M = \frac{moles_{solute}}{L_{solution}}}$$

Solute: The chemical that is dissolved into the solvent
Solvent: The liquid that the solute is dissolved into
Solution: Solvent + Solute

Typical types of Problems:

1. "Simple" Molarity Problems: ***Use:*** $\mathbf{M = \frac{mol_{solute}}{L_{solution}}}$ (How to ID problem: Contains 1 chemical and 1 concentration)

Example 1: How many grams NaCl are needed to prepare 450ml of a 0.15M NaCl solution?
Answer 1: 3.9g NaCl {1 chemical and 1 concentration → need to use M = mol/L
M = 0.15mol/L; L = 450ml x (1L/1000ml) = 0.450L; mol = x;

$0.15\text{mol/L} = \text{x}/0.450\text{L}$; x = 0.0675mol NaCl; $(0.0675\text{mol NaCl})\left(\frac{58.45\text{g NaCl}}{1\text{mol NaCl}}\right) = 3.945\text{g NaCl} = \mathbf{3.9g\ NaCl}$}

Example 2: What is the concentration of NH_4^+ when 3.50grams $(NH_4)_2S$ are added to 750. ml of water?
Answer 2: 0.136M NH_4^+ {1 chemical and 1 concentration → need to use M = mol/L but there will be an extra step for this problem;
To solve need to do this calculation: $[NH_4^+] = \text{mol } NH_4^+/L_{solution}$

$$\text{mol } NH_4^+ = (3.50\text{g } (NH_4)_2S)\left(\frac{1\text{mol } (NH_4)_2S}{68.73\text{g } (NH_4)_2S}\right)\left(\frac{2\text{mol } NH_4^+}{1\text{mol } (NH_4)_2S}\right) = 0.1018\text{mol } NH_4^+$$

$L_{solution}$ = 750ml x (1L/1000ml) = 0.750L

$$[NH_4^+] = \frac{0.1018\text{mol } NH_4^+}{0.750\text{L solution}} = 0.1358\text{M } NH_4^+ = \mathbf{0.136M\ NH_4^+}$$ }

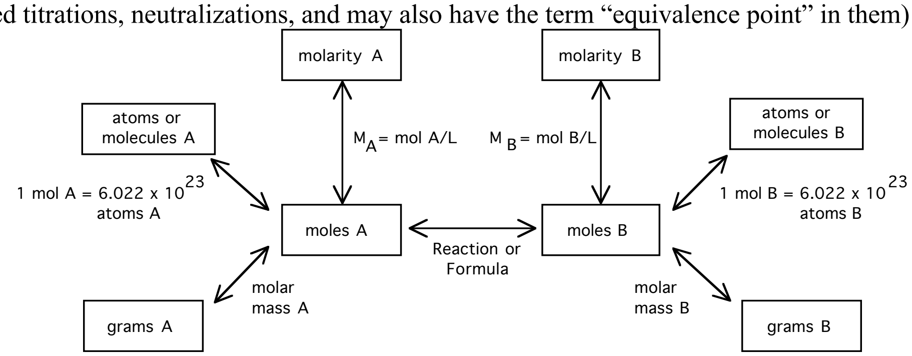
2. Dilution Problems (How to ID problem: Contains 1 chemical with 2 concentrations)

Use: $\mathbf{M_1 \times V_1 = M_2 \times V_2}$ (this is for dilutions; not reactions)

where M_1 and M_2 are the molarities of the initial and final solutions, respectively;
V_1 and V_2 are the volumes of the initial and final solutions, respectively; $V_2 = V_1$ + water added

Example 3: How many milliliters of 12.0M HCl stock solution is needed to prepare 1250mL of a 0.150M HCl solution?
Answer 3: 15.6ml {1 chemical and 2 concentrations → a dilution; need to use $M_1 \times V_1 = M_2 \times V_2$;
a "stock solution" is a concentrated solution that is kept in the stockroom and is used to prepare dilute solutions
$M_1 = 0.150M$; $V_1 = 1.25L$; $M_2 = 12.0M$; $V_2 = x$
(0.150mol/L)(1250ml) = (12.0mol/L)(x ml) (V_1 and V_2 can be in L or in ml; they must simply be in the same units)
x = 15.63ml = **15.6 ml**}

3. Stoichiometric Molarity Problems ***(use flowchart)*** (How to ID problem: Contains 2 chemicals reacting; these problems are sometimes called titrations, neutralizations, and may also have the term "equivalence point" in them)



Example 4: If it required 27.5ml of a 0.150MHCl solution to neutralize 15.5ml of $Ba(OH)_2$, what was the original concentration of the $Ba(OH)_2$?
Answer 4: 0.133M $Ba(OH)_2$ {2 chemicals → stoichiometric problem → $M_A \rightarrow M_B$ question (3 steps from the above flow chart)

Step 1: convert M_A to mol A: $M_{HCl} = mol_{HCl}/L_{HCl}$; $mol_{HCl} = M \times L = \frac{0.150M}{(27.5ml)(1L/1000ml)} = 0.004125mol\ HCl$

Step 2: convert mol HCl to mol $Ba(OH)_2$ using a balanced rxn;

$$0.004125mol\ HCl\left(\frac{1mol\ Ba(OH)_2}{2mol\ HCl}\right) = 0.0020625mol\ Ba(OH)_2$$

[hint: the stoichiometric ratio between an acid and base can be determined by ***inspection without*** writing the reaction; the ratio must be: 1 H^+ to 1 OH^- or in other words, the same number of H^+ and OH^-; since HCl has 1 H^+ and $Ba(OH)_2$ has 2 OH^-, the common factor for these two numbers is 2; so there needs to be 2 HCl (2 H^+) and 1 $Ba(OH)_2$ (2 OH^-): $2HCl(aq) + Ba(OH)_2 \rightarrow 2H_2O(l) + BaCl_2(aq)$]

Step 3: calculate the concentration using $M_{Ba(OH)2} = mol_{Ba(OH)2}/L_{Ba(OH)2}$;

$$[Ba(OH)_2] = \frac{0.0020625mol\ Ba(OH)_2}{(15.5ml)(1L/1000ml)} = 0.1331M\ Ba(OH)_2 = \mathbf{0.133M\ Ba(OH)_2}\}$$

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1. I. What is the concentration of HCl when 1.75g HCl is dissolved in water to a total volume of 250.ml?
II. a. What is the concentration of Na_3PO_4 when 1.50g of Na_3PO_4 is dissolved into a total volume of 725ml?
b. What is the Na^+ concentration? c. What is the PO_4^{-3} concentration?

2. If the concentration of $(NH_4)_3AsO_4$ is 0.50M, what is the concentration of AsO_4^{-3}? What is the concentration of NH_4^+?

3. I. How many grams of NaOH are there in 55ml of a 0.15M NaOH solution?
II. How many milliliters of 0.515M $Ba(NO_3)_2$ solution will provide 1.25grams of $Ba(NO_3)_2$?

4. I. You are asked to produce 250.ml of 0.450M Na_2S. How many milliliters of 1.25M Na_2S are required?
II. How much water must be added to a 2.15M HNO_3 solution to obtain 1.50L of a 0.750M HNO_3 solution?

5. I. How many milliliters of 0.10M NaOH solution is required to neutralized 50. ml of a 0.20M HCl solution?
II. How many milliliters of 0.75M $H_3C_6H_5O_7$, citric acid, solution is required to neutralized 50. ml of a 0.50M $Ba(OH)_2$ solution? (Note: citric acid is a triprotic acid; i.e., having 3 H^+'s)

6. I. If 26.3ml of 0.100M H_2SO_4 is titrated with 34.6ml of NaOH solution, what was the concentration of the NaOH solution.
II. If it takes 20.0ml of a 0.100M triprotic acid solution, H_3A, to neutralize 50.0ml of a $Ba(OH)_2$ solution in a titration, what was the concentration of the $Ba(OH)_2$ solution?

7. I. How many grams of Na_2S are needed to completely precipitate 355ml of a 0.275M solution of $Al(NO_3)_3$?
$2Al(NO_3)_3 + 3Na_2S \rightarrow Al_2S_3 + 6NaNO_3$
II. What volume of 0.100M HCl solution is required to react with 5.00g of $NaHCO_3$ in the following reaction?
$HCl + NaHCO_3 \rightarrow H_2O + CO_2 + NaCl$

8. It is found that 56.9ml of a 0.250M LiOH solution was needed to complete react with 1.15 grams of a monoprotic acid, HA. What is the ***molar mass*** of this unknown acid?

9. *(This is a longer and more challenging question.)* 450.ml of 1.25M $Pb(NO_3)_2(aq)$ solution was mixed with 250.ml of 2.50M KI(aq) solution and yields a solid.
a. What is the balanced molecular reaction?
b. How many moles of the solid product was formed?
c. Which reactant was the limiting reactant?
d. How many moles of the excess reactant is left over?
e. What is the concentration of the excess reactant?
f. What ions are present at the end of the reaction?

ANSWERS

1. I. [HCl] = 0.192M $\{1.75\text{g HCl}\left(\frac{1\text{mol HCl}}{36.45\text{g HCl}}\right) = 0.04801\text{mol HCl};\ [\text{HCl}] = \frac{0.04801\text{mol HCl}}{0.250\text{L solution}} = 0.1920\text{M HCl}\}$

II. a. $[Na_3PO_4]$ = 1.26 x 10^{-2}M $\{1.50\text{g Na}_3\text{PO}_4\left(\frac{1\text{mol Na}_3\text{PO}_4}{163.94\text{g Na}_3\text{PO}_4}\right) = 0.009150\text{mol Na}_3\text{PO}_4;$

$[\text{Na}_3\text{PO}_4] = \frac{0.009150\text{mol Na}_3\text{PO}_4}{0.725\text{L solution}} = 0.01262\text{M Na}_3\text{PO}_4\}$

b. $[Na^+]$ = 3.79 x 10^{-2}M $\{0.009150\text{mol Na}_3\text{PO}_4\left(\frac{3\text{mol Na}^+}{1\text{mol Na}_3\text{PO}_4}\right) = 0.02745\text{mol Na}^+;$

$[\text{Na}^+] = \frac{0.02745\text{mol Na}^+}{0.725\text{L solution}} = 0.03786\text{M Na}^+\}$

c. $[PO_4^{-3}]$ = 1.26 x 10^{-2}M $\{0.009150\text{mol Na}_3\text{PO}_4\left(\frac{1\text{mol PO}_4^{-3}}{1\text{mol Na}_3\text{PO}_4}\right) = 0.009150\text{mol PO}_4^{-3};$

$[\text{PO}_4^{-3}] = \frac{0.009150\text{mol PO}_4^{-3}}{0.725\text{L solution}} = 0.01262\text{M PO}_4^{-3}\}$

2. $[AsO_4^{-3}]$ = 0.50M $\{0.50\text{M (NH}_4)_3\text{AsO}_4\left(\frac{1\text{mol AsO}_4^{-3}}{1\text{mol (NH}_4)_3\text{AsO}_4}\right) = 0.50\text{M AsO}_4^{-3}\}$

$[NH_4^+]$ = 1.5M $\{0.50\text{M (NH}_4)_3\text{AsO}_4\left(\frac{3\text{mol NH}_4^+}{1\text{mol (NH}_4)_3\text{AsO}_4}\right) = 1.50\text{M NH}_4^+\}$

3. I. 0.33g NaOH {M = mol/L; mol = M x L = (0.15)(0.055) = 0.00825mol NaOH;
$0.00825\text{mol NaOH}\left(\frac{40.00\text{g NaOH}}{1\text{mol NaOH}}\right) = 0.330\text{g NaOH}\}$

II. 9.29ml {M = mol/L; L = mol/M; find mol $Ba(NO_3)_2$: $1.25\text{g Ba(OH)}_2\left(\frac{1\text{mol Ba(OH)}_2}{261.32\text{g Ba(OH)}_2}\right) = 0.004783\text{mol Ba(OH)}_2;$

$\text{L} = \frac{\text{mol}}{\text{M}} = \frac{0.004783\text{mol Ba(OH)}_2}{0.515\text{M Ba(OH)}_2} = 0.009287\text{L} = 9.287\text{ml}\}$

4. I. 90.0ml of 1.25M Na_2S {dilution: $M_1V_1 = M_2V_2$; (1.25M)(x ml) = (0.450M)(250ml); x = 90.0ml}
II. 0.977L water {dilution: $M_1V_1 = M_2V_2$; (2.15M)(x L) = (0.750M)(1.5L); x = 0.523L;
x = amount of 2.15M used ≠ amount of water; V_2 = total volume = V_1 + H_2O added; 1.50L = 0.523L + H_2O; H_2O = 0.977L}

5. I. 1.0 x 10^2 ml {from the flow chart: this is a $M_A \rightarrow M_B$ calculation;

Step 1: $mol_{HCl} = M_{HCl} \times L_{HCl}$ = (0.20M)(0.050L) = 0.010mol HCl;

Step 2: $0.010\text{mol HCl}\left(\frac{1\text{mol NaOH}}{1\text{mol HCl}}\right) = 0.010\text{mol NaOH}$;

Step 3: $L = \frac{\text{mol}}{M} = \frac{0.010\text{mol NaOH}}{0.10\text{M NaOH}} = 0.10\text{L} = 100\text{ml}$; the stoichiometric ratio between an acid and base can be determined by inspection without writing the reaction; the ratio must be: 1 H^+ to 1 OH^- or in other words, the same number of H^+ and OH^-; since both HCl and NaOH have 1 H^+ and 1 OH^-, respectively, the ratio between HCl and NaOH must be 1:1}

II. 22ml {from the flow chart: this is a $M_A \rightarrow M_B$ calculation;

Step 1: $mol_{Ba(OH)2} = M_{Ba(OH)2} \times L_{Ba(OH)2}$ = (0.50M)(0.050L) = 0.025mol $Ba(OH)_2$;

Step 2: $0.025\text{mol Ba(OH)}_2\left(\frac{2\text{mol } H_3C_6H_5O_7}{3\text{mol Ba(OH)}_2}\right) = 0.0167\text{mol } H_3C_6H_5O_7$;

Step 3: $L = \frac{\text{mol}}{M} = \frac{0.0167\text{mol } H_3C_6H_5O_7}{0.75\text{M } H_3C_6H_5O_7} = 0.0222\text{L} = 22.2\text{ml } H_3C_6H_5O_7$; the stoichiometric ratio between an acid and base can be determined by inspection without writing the reaction; the ratio must be: 1H^+ to 1OH^- or in other words, the same number of H^+ and OH^-; since $Ba(OH)_2$ has 2 OH^- and $H_3C_6H_5O_7$ has 3 H^+ (triprotic = 3 H^+), the common factor for these 2 numbers is 6; so there needs to be 3 $Ba(OH)_2$ (contains 6 OH^-) and 2 $H_3C_6H_5O_7$ (contains 6 H^+)}

6. I. 0.152M {from the flow chart: this is a $M_A \rightarrow M_B$ calculation;

Step 1: $mol_{H2SO4} = M_{H2SO4} \times L_{H2SO4}$ = (0.100M)(0.0263L) = 0.00263mol H_2SO_4;

Step 2: $0.00263\text{mol } H_2SO_4\left(\frac{2\text{mol NaOH}}{1\text{mol } H_2SO_4}\right) = 0.00526\text{mol NaOH}$;

Step 3: $M_{NaOH} = \frac{mol_{NaOH}}{L_{NaOH}} = \frac{0.00526\text{mol NaOH}}{0.0346\text{L}} = 0.1520\text{M NaOH}$;

the stoichiometric ratio between an acid and base can be determined by inspection without writing the reaction; the ratio must be: 1H^+ to 1OH^- or in other words, the same number of H^+ and OH^-; since H_2SO_4 has 2 H^+ and NaOH has 1 OH^-, the common factor for these 2 numbers is 2; so there needs to be
1 H_2SO_4 (contains 2 H^+) and 2 NaOH (contains 2 OH^-)}

II. 0.0600M {from the flow chart: this is a $M_A \rightarrow M_B$ calc; let H_3A be a triprotic acid;

Step 1: $mol_{H3A} = M_{H3A} \times L_{H3A}$ = (0.100M)(0.0200L) = 0.00200mol H_3A;

Step 2: $0.00200\text{mol } H_3A\left(\frac{3\text{mol Ba(OH)}_2}{2\text{mol } H_3A}\right) = 0.00300\text{mol Ba(OH)}_2$;

Step 3: $M_{Ba(OH)_2} = \frac{mol_{Ba(OH)_2}}{L_{Ba(OH)_2}} = \frac{0.00300\text{mol}}{0.0500\text{L}} = 0.0600\text{M Ba(OH)}_2$; the stoichiometric ratio between an acid and base can be determined by inspection without writing the reaction; the ratio must be: 1H^+ to 1OH^- or in other words, the same number of H^+ and OH^-; since H_3A has 3 H^+ and $Ba(OH)_2$ has 2 OH^-, the common factor for these two numbers is 6; so there needs to be 2 H_3A (contains 6 H^+) and 3 $Ba(OH)_2$ (contains 6 OH^-)}

7. I. 11.4g Na_2S {this is a $M_A \rightarrow g_B$ calc; $mol_{Al(NO3)3} = M_{Al(NO3)3} \times L_{Al(NO3)3}$ = (0.275M)(0.355L) = 0.09763mol $Al(NO_3)_3$; $\left(0.09763\text{mol Al(NO}_3)_3\right)\left(\frac{3\text{mol } Na_2S}{2\text{mol Al(NO}_3)_3}\right)\left(\frac{78.04\text{g } Na_2S}{1\text{mol } Na_2S}\right) = 11.425\text{g } Na_2S$ }

II. 0.595L {this is a $g_A \rightarrow M_B$ calculation; $\left(5.00\text{g NaHCO}_3\right)\left(\frac{1\text{mol NaHCO}_3}{84.01\text{g NaHCO}_3}\right)\left(\frac{1\text{mol HCl}}{1\text{mol NaHCO}_3}\right) = 0.05952\text{mol HCl}$

$L_{HCl} = \frac{mol_{HCl}}{M_{HCl}} = \frac{0.05952\text{mol}}{0.100\text{M}} = 0.5952\text{L HCl}$ }

8. 80.8g/mol {this is a $M_A \rightarrow mol_B$; molar mass = grams HA/mol HA; find mol LiOH from titration data: 0.0569L x 0.25M = 0.01423mol LiOH; reaction: LiOH + HA → H_2O + LiA;

$$0.01423\text{mol LiOH}\left(\frac{1\text{mol HA}}{1\text{mol LiOH}}\right) = 0.01423\text{mol HA}\text{ ; molar mass} = \frac{\text{grams HA}}{\text{mol HA}} = \frac{1.15\text{g HA}}{0.01423\text{mol HA}} = 80.84\text{g / mol}$$ }

9. a. $Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$

b. 0.313mol PbI_2 {this is a limiting reagent question since 2 reactant quantities were given; the calculation is: $M_A \rightarrow mol_B$ done twice;

$Pb(NO_3)_2$: mol $Pb(NO_3)_2$ = M x L = (1.25M)(0.450L) = 0.5625mol $Pb(NO_3)_2$;

$$\left(0.5625\text{mol Pb(NO}_3)_2\right)\left(\frac{1\text{mol PbI}_2}{1\text{mol Pb(NO}_3)_2}\right) = 0.5625\text{mol PbI}_2\text{ ;}$$

KI: mol KI = M x L = (2.50M)(0.250L) = 0.625mol KI; $\left(0.625\text{mol KI}\right)\left(\frac{1\text{mol PbI}_2}{2\text{mol KI}}\right) = 0.3125\text{mol PbI}_2$ }

c. KI {KI produced the smaller amount of product so it is the limiting reagent}

d. 0.250mol $Pb(NO_3)_2$ {left overs = starting amount – amount used; for amount used the calculation is: LR → EX;

$$\left(0.625\text{mol KI}\right)\left(\frac{1\text{mol Pb(NO}_3)_2}{2\text{mol KI}}\right) = 0.3125\text{mol Pb(NO}_3)_2\text{ used ; left overs} = 0.5625\text{mol} - 0.3125\text{mol} = 0.250\text{mol Pb(NO}_3)_2$$ }

e. 0.357M $\{[Pb(NO_3)_2] = \frac{\text{mol Pb(NO}_3)_2}{L_{total}} = \frac{0.250\text{mol Pb(NO}_3)_2}{(450\text{ml} + 250\text{ml}) / 1000} = 0.357\text{M}\}$

f. Pb^{+2}, NO_3^-, and K^+ {$Pb(NO_3)_2(aq)$, $PbI_2(s)$, and $2KNO_3(aq)$ exist at the end of the reaction; ignore $PbI_2(s)$ since it is a solid; the other two chemicals dissolve yielding: Pb^{+2}, NO_3^-, and K^+}