Nuggets: Molarity, Dilutions, Stoichiometry with M (Titrations); Enthalpy of a rxn (proportionality calculations)

CHAPTER 4, Section 4.6a (do this section of Chapter 4 if included on Exam 1; skip if not)
Heat: amount of energy flow from one area to another
Exothermic: energy is released from the system
Endothermic: energy is absorbed by the system

Units of heat = J (joules) (J = kg (m^2/s^2)
Enthalpy = H; Change in enthalpy = ΔH; Change in Enthalpy: the heat of the reaction at constant pressure
Sign of ΔH: ΔH < 0 (-) → exothermic (heat released); ΔH > 0 (+) → endothermic (heat absorbed);

Enthalpy Changes for a Chemical Reaction – scaling a reaction up or down (proportionality)
mol quantity_1 (from rxn) / heat_1(from Δr_H) = quantity_2 / heat_2 quantity_1 = #mol from balanced rxn; heat_1 = heat from balanced rxn = Δ_r_H;
quantity_2 = mass or mol given or asked for in the question;
heat_2 = heat associated with quantity_2 and is either given or asked for in the question

Example 4: How much heat is released when 16.0g O_2 reacts in this rxn: 2CuS + 3O_2 → 2CuO + 2SO_2 Δ_r_H = -193 kJ/mol
Answer 4: \[
\frac{3\text{molO}_2}{-193\text{kJ/mol}} = \frac{16.0\text{gO}_2}{x} \quad \text{or}\quad \frac{3\text{molO}_2}{-193\text{kJ/mol}} = \frac{0.500\text{molO}_2}{x} \quad \text{or}\quad x = \frac{0.500\text{molO}_2}{3\text{molO}_2}(-193\text{kJ}) = -32.2kJ
\]

Another way to set up this problem: \[
16\text{gO}_2 \left( \frac{1\text{molO}_2}{32\text{gO}_2} \right) \left( \frac{-193\text{kJ}}{3\text{molO}_2} \right) = -32.2kJ
\]

Example 5: When 12.5g Fe is reacted in the following reaction 19.9kJ are evolved. What is the enthalpy of reaction, Δ_r_H for the reaction?
3Fe(s) + 2O_2(g) → Fe_3O_4(s)
Answer 5: \[
\frac{12.5\text{gFe}}{-19.9kJ} = \frac{3\text{molFe}}{x} \quad \text{or}\quad \frac{0.2238\text{molFe}}{-19.9kJ} = \frac{3\text{molFe}}{x} \quad \text{or}\quad 0.2238x = -59.7; x = -266.8kJ = Δ_r_H
\]

Another way to set up this problem: \[
\frac{-19.9kJ}{12.5\text{gFe}} \left( \frac{55.85\text{gFe}}{1\text{molFe}} \right) \frac{3\text{molFe}}{-266.7kJ} = Δ_r_H
\]

CHAPTER 3
MOLARITY – concentration of solutions; abbreviated as M (pronounced “molar”)

\[ M = \frac{\text{moles}_{\text{solute}}}{L_{\text{solution}}} \]

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

Types of Problems:
1. “Simple” Molarity Problems: Use: \[ M = \text{mol/L} \] (ID question: 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: 1 chemical and 1 concentration – need to use M = mol/L
M = 0.15mol/L; L = 450ml x (1L/1000ml) = 0.450L; mol = x;
0.15mol/L = x/0.450L; x = 0.0675mol NaCl
0.0675mol NaCl x (58.45g NaCl/1mol NaCl) = 3.945g NaCl = 3.9g NaCl
2. Dilution Problems (ID question: Problem contains 1 chemical and 2 concentrations)

Use: \( M_1 \times V_1 = M_2 \times V_2 \) (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; \( V_2 = V_1 + \text{water added} \)

Example 2: How many milliliters 12.0M HCl stock solution is needed to prepare 1250L of a 0.150M HCl solution?
Answer 2: 1 chemical and 2 concentrations – a dilution; need to use \( M_1 \times V_1 = M_2 \times V_2 \)

(a “stock solution” is simply a concentrated solution that is kept in the stockroom and is used to prepare dilute solutions)

\( M_1 = 0.150 \text{M}; \quad V_1 = 1.25 \text{L}; \quad M_2 = 12.0 \text{M}; \quad V_2 = x \)

\[ (0.150 \text{mol/L})(1250 \text{ml}) = (12.0 \text{mol/L})(x \text{ ml}) \quad (V_1 \text{ and } V_2 \text{ can be L or ml; they must simply be the same units}) \]

\[ x = 15.63 \text{ml} = 15.6 \text{ ml} \]

3. Stoichiometric Molarity Problems (ID question: Problem contains 2 chemicals; these problems are sometimes called titrations, neutralizations, reactions, and may also have the term “equivalence point” in them)

Use: the flowchart

\[ \begin{align*}
\text{atoms or molecules A} & \quad \text{molarity A} \\
1 \text{ mol A} & = 6.022 \times 10^{23} \text{ atoms A} \\
\text{molar mass A} & \quad \text{moles A} \\
\text{Reaction or Formula} & \quad \text{molar mass B} \\
1 \text{ mol B} & = 6.022 \times 10^{23} \text{ atoms B} \\
\text{grams A} & \quad \text{grams B} \\
\text{molarity B} &
\end{align*} \]

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

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

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

\[ 0.004125 \text{mol HCl} \times (1 \text{mol Ba(OH)\(_2\)}/2 \text{mol HCl}) = 0.0020625 \text{mol Ba(OH)\(_2\)} \]

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

Step 3: calculate the concentration using \( M_{\text{Ba(OH)\(_2\)}} = \text{mol Ba(OH)\(_2\)/L Ba(OH)\(_2\)}; \quad M_{\text{Ba(OH)\(_2\)}} = (0.0020625 \text{mol Ba(OH)\(_2\)})(15.5 \text{ml/1000ml}) = 0.1375 \text{M} = 0.138 \text{M} \)

Chapter 4, Section 4.6a
1. Use the reaction shown to answer the following questions.

\[ \text{P}_4\text{S}_3(s) + 8\text{O}_2(g) \rightarrow \text{P}_4\text{O}_{10}(s) + 3\text{SO}_2(g) \quad \Delta H^\circ = -3677 \text{kJ} \]
a. How much heat would be released if 5.000mol \( \text{P}_4\text{S}_3(s) \) were consumed?
b. How much heat would be released if 25.00g \( \text{O}_2(g) \) were consumed?
2. Use the reaction shown to answer the following questions.

\[ \text{C}_3\text{H}_8(g) + 5\text{O}_2(g) \rightarrow 3\text{CO}_2(g) + 4\text{H}_2\text{O}(g) \quad \Delta H^\circ = -2044\text{kJ} \]

a. How much heat would be released if 10.0mol \text{O}_2(g) were consumed?

b. How much heat would be released if 100.0g \text{CO}_2(g) were produced?

3. Is the process to boil water an endothermic or exothermic process?

4. What is the concentration of HCl when 1.75g HCl is dissolved in water to a total volume of 250.ml?

b. What is the concentration of Na\(^+\) when 2.50g NaCl is dissolved in water to a total volume of 500.ml?

c. What is the concentration of H\(^+\) when 3.00 x 10\(^{-2}\)g of H\(_2\)SO\(_4\) (strong acid; assume 2 H\(^+\) come off) dissolved in water to a total volume of 125ml.

d. What is the concentration of Na\(_3\)PO\(_4\) when 1.50g of Na\(_3\)PO\(_4\) is dissolved in to a total volume of 725ml? What is the Na\(^+\) concentration? What is the PO\(_4\)^{3-}\ concentration?

5. a. If the concentration of Na\(_2\)SO\(_4\) is 0.15M, what is the concentration of Na\(^+\)?

b. If the concentration of (NH\(_4\))\(_3\)AsO\(_4\) is 0.50M, what is the concentration of AsO\(_4\)^{3-}? Concentration of NH\(_4^+\)?

6. a. How many grams of NaOH are there in 55ml of a 0.15M NaOH solution?

b. How many milliliters of 0.126M HClO\(_4\) are required to give 0.00752mol HClO\(_4\)?

c. How many grams of HCl must be added to yield a 150.ml solution with a [H\(^+\)] = 3.16 x 10\(^{-3}\) M?

d. How many milliliters of 0.515M Ba(NO\(_3\))\(_2\) solution will provide 1.25grams of Ba(NO\(_3\))\(_2\)?

7. a. You are asked to produce 250.ml of 0.450M Na\(_2\)S. How many milliliters of 1.25M Na\(_2\)S are required?

b. You are asked to produce 2.0L of 0.25M Na\(_3\)N. How many liters of 1.5M Na\(_3\)N are required?

c. How much water must be added to yield a 2.15M HNO\(_3\) solution to obtain 1.50L of a 0.750M HNO\(_3\) solution?

d. To what final volume should 25ml of 2.4M K\(_2\)Cr\(_2\)O\(_7\) be diluted to give a solution that is 0.10M K\(_2\)Cr\(_2\)O\(_7\)?

8. a. How many milliliters of 0.10M NaOH solution is required to neutralized 50. ml of a 0.20M HCl solution?

b. How many milliliters of 0.75M H\(_3\)C\(_6\)H\(_5\)O\(_7\), 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)

9. a. If 26.3ml of 0.100M H\(_2\)SO\(_4\) is titrated with 34.6ml of NaOH solution, what was the concentration of the NaOH solution.

b. If it takes 12.5ml of a 0.400M HCl solution to neutralize 25.0ml of a Ca(OH\(_2\)) solution in a titration, what was the concentration of the Ca(OH\(_2\)) solution?

c. If it takes 20.0ml of a 0.100M triprotic acid solution, H\(_3\)A, to neutralize 50.0ml of a Ba(OH\(_2\)) solution in a titration, what was the concentration of the Ba(OH\(_2\)) solution?

10. a. How many grams of NaCl are needed to completely precipitate 125ml of a 0.150M of a AgNO\(_3\) solution?

\[ \text{AgNO}_3 + \text{NaCl} \rightarrow \text{AgCl} + \text{NaNO}_3 \]

b. How many grams of Na\(_2\)S are needed to completely precipitate 355ml of a 0.275M of a Al(NO\(_3\))\(_3\) solution?

\[ 2\text{Al(NO}_3)_3 + 3\text{Na}_2\text{S} \rightarrow \text{Al}_2\text{S}_3 + 6\text{NaNO}_3 \]

c. What volume of a 0.100M HCl solution is required to react with 5.00g of NaHCO\(_3\) in the following reaction?

\[ \text{HCl} + \text{NaHCO}_3 \rightarrow \text{H}_2\text{O} + \text{CO}_2 + \text{NaCl} \]
11. What volume of 0.10M H₂SO₃ is need to titrate 24.0ml of 0.20M Fe⁺³ given the following reaction: 

\[ 2\text{Fe}^{+3} + \text{H}_2\text{SO}_3 + \text{H}_2\text{O} \rightarrow 2\text{Fe}^{+2} + \text{SO}_4^{2-} + 4\text{H}^+ \]

12. 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?

ANSWERS

1. a. \(-18,385\text{kJ}\) \(\text{\{proportionality of heats: 1mol P}_4\text{S}_3(s)/-3677kJ = 5mol P}_4\text{S}_3(s)/xkJ;\) cross multiply: \(-18385kJ = x\}\)

b. \(-359.1\text{kJ}\) \(\text{\{proportionality of heats: 8mol O}_2/-3677kJ = 25g O}_2/xkJ;\) convert 8mol O₂ to grams O₂:

\[ 8\text{mol O}_2 \times (32g \text{O}_2/1\text{mol O}_2) = 256g \text{ O}_2 \rightarrow 256g \text{ O}_2/-3677kJ = 25g \text{ O}_2/xkJ \rightarrow x = -359.1\text{kJ}\]

2. a. \(-4,088\text{kJ}\) \(\text{\{proportionality of heats: 5mol O}_2(g)/-2044kJ = 10mol O}_2(g)/xkJ;\) cross multiply: \(-20440kJ = 5x; x = -4088kJ\}

b. \(-1548\text{kJ}\) \(\text{\{proportionality of heats: 3mol CO}_2/-2044kJ = 100g CO}_2/xkJ;\) convert 3mol CO₂ to grams CO₂:

\[ 3\text{mol CO}_2 \times (44.0g \text{CO}_2/1\text{mol CO}_2) = 132g \text{CO}_2 \rightarrow 132g \text{CO}_2/-2044kJ = 100g \text{CO}_2/xkJ;\] cross multiply: \(132x = -204400;\)

\[ x = -1548kJ\]

3. Endothermic as it requires heat to boil water and endothermic means to absorb heat.

4. a. [H⁺] = 0.192M \(\text{\{1.75g HCl x (1mol HCl/36.46g HCl) = 0.04800mol HCl/0.250L = 0.1920M}\}}\)

b. [Na⁺] = 0.0856M \(\text{\{2.50g NaCl x (1mol NaCl/58.44g NaCl) x (1mol Na}^+/1\text{mol NaCl}) = 0.04278mol NaCl/0.500L = 0.0856M\}}\)

c. [H⁺] = 4.90 \times 10⁻³M \(\text{\{3.00 \times 10⁻²g H}_2\text{SO}_4 \times (1mol H}_2\text{SO}_4/98.08g H}_2\text{SO}_4 \times (2mol H}^+/1\text{mol H}_2\text{SO}_4) = 0.0006117mol NaCl/0.125L = 0.004894M\} \)

5. a. [Na⁺] = 0.30M \(\text{\{0.15g Na}_2\text{SO}_4 x (2Na}^+/1\text{Na}_2\text{SO}_4) = 0.30M Na}^+\}

b. [AsO₄³⁻] = 0.50M \(\text{\{0.50M (NH}_4)_2\text{AsO}_4 x (1\text{AsO}_₄^{3-}/1(NH}_4)_2\text{AsO}_4) = 0.50M AsO}_₄^{3-}\}

\[ [\text{NH}_4^+] = 1.5M \text{\{0.50M (NH}_4)_2\text{AsO}_4 x (3\text{NH}_4^+/1(NH}_4)_2\text{AsO}_4) = 1.50M NH}_4^+\]

6. a. 0.33g NaOH \(\text{\{M = mol/L; mol = M x L = (0.15)(0.055) = 0.00825mol NaOH x (40.00g NaOH/1mol NaOH) = 0.330g NaOH\}}\)

b. 59.7 ml \(\text{\{M = mol/L; L = mol/M = (0.00752)/(0.126) = 0.05968L x 1000ml/1L = 59.68ml\}}\)

c. 0.0173 g \(\text{\{M = mol/L; mol = M x L = (3.16 x 10⁻³)(0.150) = 0.000474mol HCl x (36.46g HCl/1mol HCl) = 0.01728g HCl\}}\)

d. 9.29ml \(\text{\{M = mol/L; L = mol/M; find mol Ba(NO}_3)_2: 1.25g Ba(NO}_3)_2 x (1mol Ba(NO}_3)_2/261.32g Ba(NO}_3)_2) = 0.004783mol Ba(NO}_3)_2; L = mol/M = (0.004783)/(0.515) = 0.009287L x 1000ml/1L = 9.287ml\}}\)

7. a. 90.0ml of 1.25M Na₂S \(\text{\{dilution: M}_1\text{V}_1 = M}_2\text{V}_2; (1.25)(x) = (0.450)(250); x = 90.0ml\}}\)

b. 0.33 L \(\text{\{dilution: M}_1\text{V}_1 = M}_2\text{V}_2; (1.5)(x) = (0.25)(2); x = 0.333L\}

c. 0.977L water \(\text{\{dilution: M}_1\text{V}_1 = M}_2\text{V}_2; (2.15)(x) = (0.750)(1.5); x = 0.523L; x = \text{amount of 2.15M used ≠ amount of water; V}_2 = \text{total volume} = V_1 + H}_2\text{O added; 1.50} = 0.523 + H}_2\text{O; H}_2\text{O} = 0.977L\}

d. 6.0 \times 10² ml \(\text{\{dilution: M}_1\text{V}_1 = M}_2\text{V}_2; (2.4)(25) = (0.10)(x); x = 600ml\}
8. a. 1.0 x 10^2 ml 
{using the flow chart, this is a M_A to M_B calculation; mol_{HCl} = M_{HCl} x L_{HCl} = (0.20)(0.050) = 0.010mol HCl; 0.010mol HCl x (1mol NaOH/1mol HCl) = 0.010mol NaOH; L_{NaOH} = mol_{NaOH}/M_{NaOH} = 0.010/0.10 = 0.10L x (1000ml/1L) = 100ml 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 both HCl and NaOH have 1 H^+ or OH^-, respectively, the ratio of HCl to NaOH must be 1:1}

b. 22ml 
{using the flow chart, this is a M_A to M_B calculation; mol_{Ba(OH)2} = M_{Ba(OH)2} x L_{Ba(OH)2} = (0.50)(0.050) = 0.025mol Ba(OH)2; 0.025mol Ba(OH)2 x (2mol H_3C_6H_5O_7/3mol Ba(OH)2) = 0.0167mol H_3C_6H_5O_7; L_{H_3C_6H_5O_7} = mol_{H_3C_6H_5O_7}/M_{H_3C_6H_5O_7} = 0.0167/0.75 = 0.0222L x (1000ml/1L) = 22.2ml 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 (6 OH^-) and 2 H_3C_6H_5O_7 (6 H^+)}

9. a. 0.152M 
{using the flow chart, this is a M_A to M_B calculation; mol_{H_2SO_4} = M_{H_2SO_4} x L_{H_2SO_4} = (0.100)(0.0263) = 0.00263mol H_2SO_4; 0.00263mol H_2SO_4 x (2mol NaOH/1mol H_2SO_4) = 0.00526mol NaOH; M_{NaOH} = mol_{NaOH}/L_{NaOH} = 0.00526/0.0346 = 0.1520M 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 (2 H^+) and 2 NaOH (2 OH^-)}

b. 0.100M 
{using the flow chart, this is a M_A to M_B calculation; mol_{HCl} = M_{HCl} x L_{HCl} = (0.400)(0.0125) = 0.00500mol HCl; 0.00500mol HCl x (1mol Ca(OH)_2/2mol HCl) = 0.00250mol Ca(OH)_2; M_{Ca(OH)_2} = mol_{Ca(OH)_2}/L_{Ca(OH)_2} = 0.00250/0.0250 = 0.1000M Ca(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 HCl has 1 H^+ and Ca(OH)_2 has 2 OH^-, the common factor for these 2 numbers is 2; so there needs to be 2 HCl (2 H^+) and 1 Ca(OH)_2 (2 OH^-)}

c. 0.0600M 
{using the flow chart, this is a M_A to M_B calculation; let H_3A be a triprotic acid; mol_{H_3A} = M_{H_3A} x L_{H_3A} = (0.100)(0.0200) = 0.00200mol H_3A; 0.00200mol H_3A x (3mol Ba(OH)_2/2mol H_3A) = 0.00300mol Ba(OH)_2; M_{Ba(OH)_2} = mol_{Ba(OH)_2}/L_{Ba(OH)_2} = 0.00300/0.0500 = 0.0600M 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 2 numbers is 6; so there needs to be 2 H_3A (6 H^+) and 3 Ba(OH)_2 (6 OH^-)}

10. a. 1.10g NaCl 
{using the flow chart, this is a M_A to m_B calculation; mol_{AgNO_3} = M_{AgNO_3} x L_{AgNO_3} = (0.150)(0.125) = 0.01875mol AgNO_3; 0.01875mol AgNO_3 x (1mol NaCl/1mol AgNO_3) = 0.01875mol NaCl x (58.44g NaCl/1mol NaCl) = 1.0958g NaCl}

b. 11.4g Na_2S 
{using the flow chart, this is a M_A to m_B calculation; mol_{Al(NO_3)_3} = M_{Al(NO_3)_3} x L_{Al(NO_3)_3} = (0.275)(0.355) = 0.09763mol Al(NO_3)_3; 0.09763mol Al(NO_3)_3 x (3mol Na_2S/2mol Al(NO_3)_3) = 0.1464mol Na_2S x (78.04g Na_2S/1mol Na_2S) = 11.425g Na_2S}

c. 0.595L 
{using the flow chart, this is a g_A to M_B calculation; 5.00g NaHCO_3 x (1mol NaHCO_3/84.01g NaHCO_3) = 0.05952mol NaHCO_3; 0.05952mol NaHCO_3 x (1mol HCl/1mol NaHCO_3) = 0.05952mol HCl; L_{HCl} = mol_{HCl}/M_{HCl} = (0.05952)/(0.100) = 0.5952L HCl}

11. 4.8ml 
{0.024L(0.20M) = 0.0048mol Fe^{3+}; 0.0048mol Fe^{3+}(1mol H_2SO_4/2mol Fe^{3+}) = 0.0024mol H_2SO_4; M = mol/L; L = mol/M; L_{H_2SO_4} = mol_{H_2SO_4}/M_{H_2SO_4} = 0.0024mol/0.50M = 0.0048L = 4.8ml}

12. 80.8g/mol 
{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 \rightarrow H_2O + LiA; 0.01423mol LiOH x (1mol HA/1mol LiOH) = 0.01423mol HA; molar mass = grams HA/mol HA = 1.15g HA/0.01423mol HA = 80.84g/mol}