Ch. 10 Notes – STOICHIOMETRY

NOTE: Vocabulary terms are in **boldface and underlined**. Supporting details are in *italics.*

1 MOLE = 6.02×10^{23} representative particles
representative particles = ATOMS, IONS, MOLECULES, & FORMULA UNITS ("funs")

CONVERSION FACTOR SUMMARY:

$\frac{6.02 \times 10^{23} \text{ representative particles}}{1 \text{ MOLE}}$	$\frac{1 \text{ MOLE}}{6.02 \times 10^{23} \text{ representative particles}}$
$\frac{\text{MOLAR MASS (g)}}{1 \text{ MOLE}}$	$\frac{1 \text{ MOLE}}{\text{MOLAR MASS (g)}}$
$\frac{22.4 \text{ L (for a gas at STP)}}{1 \text{ MOLE}}$	$\frac{1 \text{ MOLE}}{22.4 \text{ L (for a gas at STP)}}$

I. Stoichiometry

A. **stoichiometry**—using balanced chemical equations to obtain info.

B. information from a balanced equation

1) *numbers of particles*: atoms, ions, molecules, formula units
2) *numbers of moles = mole ratios = coefficient ratios*
3) *mass* = molecular masses from the periodic table
4) *volume*, if at STP, 22.4 L = 1 mol of gas

Only mass and number of atoms are conserved (reactant numbers = product numbers).

	_2_ $H_2(g)$	+ ___O_2 (g)	→	_2_ H_2O (g)
atoms in balancing	4 H	2 O	=	4 H, 2 O
r.p.	2 molecules	1 molecule		2 molecules
mol	2 mol	1 mol		2 mol
g	4(1.01) = 4.04	2(16.00) = 32.00	=	2(18.02) = 36.04
L (STP)	2(22.4) = 44.8	22.4		2(22.4) = 44.8

II. Mole - Mole (MOL – MOL) Conversions

A. the most important, most basic stoich calculation

B. *uses the coefficients of a balanced equation* to compare the amounts of reactants and products

C. *coefficients are mole ratios*

D. *the way to go from substance A to substance B*

E. **mol – mol is the only time the mole number in the conversion is not automatically 1.** (Avogadro's #, molar mass, and 22.4 L (STP) are all equal to 1 mole.)

MOL – MOL : $\frac{\text{\# mol B}}{\text{\# mol A}}$ **(new, ending substance – what is being asked for)** / **(old, starting substance – what is given originally)**

 # = coefficients

F. examples

EXAMPLE 1) How many moles of carbon monoxide are produced when carbon reacts with 0.750 mol of oxygen?

Unbalanced: $C + O_2 \rightarrow CO$ Balanced: $2C + O_2 \rightarrow 2CO$

$$0.750\ \cancel{mol\ O_2} \times \frac{2\ mol\ CO}{1\ \cancel{mol\ O_2}} = \boxed{1.50\ mol\ CO}$$

EXAMPLE 2) Aluminum reacts with oxygen gas to form aluminum oxide. Find the number of moles of both reactants, if 0.661 mol of product is formed.

$Al + O_2 \rightarrow Al_2O_3$ $4Al + 3O_2 \rightarrow 2Al_2O_3$

$$0.661\ \cancel{mol\ Al_2O_3} \times \frac{4\ mol\ Al}{2\ \cancel{mol Al_2O_3}} = \boxed{1.32\ mol\ Al}$$

$$0.661\ \cancel{mol\ Al_2O_3} \times \frac{3\ mol\ O_2}{2\ \cancel{mol Al_2O_3}} = \boxed{0.992\ mol\ O_2}$$

III. **<u>MASS – MASS Conversions</u> – Using molar mass in stoich problems to predict masses of reactants and/or products**

A. a balanced chemical equation can be used to compare masses of reactants and products

B. *mass – mass* cannot change which substance you are dealing with; only *mol – mol* can do that

"MASS – MASS": $\frac{\textbf{GIVEN g A}}{} \times \frac{\textbf{1 mol A}}{\textbf{\textit{PT} g A}} \times \frac{\textbf{\textit{CE} mol B}}{\textbf{\textit{CE} mol A}} \times \frac{\textbf{\textit{PT} g B}}{\textbf{1 mol B}}$

PT = periodic table, molar mass ***CE = coefficients***

C. examples

EXAMPLE 3) How many grams of hydrochloric acid are made from the reaction of 0.500 g of hydrogen gas with excess chlorine gas?

$H_2 + Cl_2 \rightarrow HCl$ $H_2 + Cl_2 \rightarrow 2HCl$

GAME PLAN: KNOWN, PER.TABLE, COEFF., PER.TABLE

$$0.500\ \cancel{g\ H_2} \times \frac{1\ \cancel{mol\ H_2}}{2.02\ \cancel{g\ H_2}} \times \frac{2\ \cancel{mol\ HCl}}{1\ \cancel{mol\ H_2}} \times \frac{36.46\ g\ HCl}{1\ \cancel{mol\ HCl}} = \boxed{18.0\ g\ HCl}$$

EXAMPLE 4) Calculate the numbers of grams of products formed when 25.0 g of sodium nitrate decomposes into sodium nitrite and oxygen.

$NaNO_3 \rightarrow NaNO_2 + O_2$ $2NaNO_3 \rightarrow 2NaNO_2 + O_2$

$$25.0\ \cancel{g\ NaNO_3} \times \frac{1\ \cancel{mol\ NaNO_3}}{84.99\ \cancel{g\ NaNO_3}} \times \frac{2\ \cancel{mol\ NaNO_2}}{2\ \cancel{mol\ NaNO_3}} \times \frac{69.00\ g\ NaNO_2}{1\ \cancel{mol\ NaNO_2}} = \boxed{20.3\ g\ NaNO_2}$$

$$25.0\ \cancel{g\ NaNO_3} \times \frac{1\ \cancel{mol\ NaNO_3}}{84.99\ \cancel{g\ NaNO_3}} \times \frac{1\ \cancel{mol\ O_2}}{2\ \cancel{mol\ NaNO_3}} \times \frac{32.00\ g\ O_2}{1\ \cancel{mol\ O_2}} = \boxed{4.71\ g\ O_2}$$

IV. MOLE–MASS (or MASS– MOLE) Conversions

"MASS – MOLE":

$$\frac{\text{GIVEN g A}}{} \times \frac{1 \text{ mol A}}{PT \text{ g A}} \times \frac{CE \text{ mol B}}{CE \text{ mol A}}$$

"MOLE – MASS":

$$\frac{\text{GIVEN mol A}}{} \times \frac{CE \text{ mol B}}{CE \text{ mol A}} \times \frac{PT \text{ g B}}{1 \text{ mol B}}$$

PT = periodic table, molar mass ***CE = coefficients***

EXAMPLE 5) How many g of water are produced from the complete combustion of C_2H_2?

$C_2H_2 + O_2 \rightarrow CO_2 + H_2O$ $\underline{2}C_2H_2 + \underline{5}O_2 \rightarrow \underline{4}CO_2 + \underline{2}H_2O$

$$0.6829 \text{ mol } C_2H_2 \times \frac{2 \text{ mol } H_2O}{2 \text{ mol } C_2H_2} \times \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} = \boxed{12.31 \text{ g } H_2O}$$

EXAMPLE 6) Using the equation $\underline{2}C_2H_2 + \underline{5}O_2 \rightarrow \underline{4}CO_2 + \underline{2}H_2O$ how many moles of O_2 would be needed to produce 56.09 g of CO_2?

$$56.09 \text{ g } CO_2 \times \frac{1 \text{ mol } CO_2}{44.01 \text{ g } CO_2} \times \frac{5 \text{ mol } O_2}{4 \text{ mol } CO_2} = \boxed{1.593 \text{ mol } O_2}$$

V. MASS-VOLUME (or VOLUME – MASS) Conversions -

Using molar volume in stoich problems

"MASS – VOLUME": (gases @ STP)

$$\frac{\text{GIVEN g A}}{} \times \frac{1 \text{ mol A}}{PT \text{ g A}} \times \frac{CE \text{ mol B}}{CE \text{ mol A}} \times \frac{22.4 \text{ L B}}{1 \text{ mol B}}$$

"VOLUME – MASS": (gases @ STP)

$$\frac{\text{GIVEN L A}}{} \times \frac{1 \text{ mol A}}{22.4 \text{ L A}} \times \frac{CE \text{ mol B}}{CE \text{ mol A}} \times \frac{PT \text{ g B}}{1 \text{ mol B}}$$

PT = periodic table, molar mass ***CE = coefficients***

EXAMPLE 7) How many L of oxygen are produced from the decomposition of 3.50 g of water at STP?

$H_2O \rightarrow H_2 + O_2$ $\underline{2}H_2O \rightarrow \underline{2}H_2 + O_2$

$$3.50 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} \times \frac{1 \text{ mol } O_2}{2 \text{ mol } H_2O} \times \frac{22.4 \text{ L } O_2}{1 \text{ mol } O_2} = \boxed{2.17 \text{ L } O_2}$$

EXAMPLE 8) Using the equation $\underline{2}C_2H_2 + \underline{5}O_2 \rightarrow \underline{4}CO_2 + \underline{2}H_2O$, how many liters of oxygen gas are needed when 5.02 g of C_2H_2 undergoes complete combustion under STP conditions?

$$5.02 \text{ g } C_2H_2 \times \frac{1 \text{ mol } C_2H_2}{26.04 \text{ g } C_2H_2} \times \frac{5 \text{ mol } O_2}{2 \text{ mol } C_2H_2} \times \frac{22.4 \text{ L } O_2}{1 \text{ mol } O_2} = \boxed{10.8 \text{ L } O_2}$$

VI. VOLUME-VOLUME Conversions

"VOLUME – VOLUME": (gases @ STP)

GIVEN L A x **1 mol A / 22.4 L A** x ***CE* mol B / *CE* mol A** x **22.4 L B / 1 mol B**

CE = coefficients ***(SHORT CUT: compare coefficients!)***

EXAMPLE 9) How many liters of carbon dioxide are produced from 0.252 L of hydrochloric acid reacting with excess sodium bicarbonate?

$NaHCO_3$ + HCl → NaCl + CO_2 + H_2O

0.252 ~~L HCl~~ x 1 ~~mol HCl~~ / ~~22.4 L HCl~~ x 1 ~~mol CO_2~~ / 1 ~~mol HCl~~ x ~~22.4~~ L CO_2 / 1 ~~mol CO_2~~ = **0.252 L CO_2**

SHORTCUT: coefficients = 1 mol HCl to 1 mol CO_2. , so 0.252 L HCl = **0.252 L CO_2**

EXAMPLE 10) How many L of sulfur trioxide are produced from the reaction of 36.1 L of oxygen with sulfur dioxide at STP?

SO_2 + O_2 → SO_3 2SO_2 + O_2 → 2SO_3

36.1 ~~L O_2~~ x 1 ~~mol O_2~~ / ~~22.4 L O_2~~ x 2 ~~mol SO_3~~ / 1 ~~mol O_2~~ x ~~22.4~~ L SO_3 / 1 ~~mol SO_3~~ = **72.2 L SO_3**

SHORTCUT: coefficient of O_2 = 1; coefficient of SO_3 = 2 36.1 L x 2 = **72.2 L SO_3**

VII. MASS – PARTICLE (or PARTICLE-MASS) Conversions

"MASS – PARTICLE": (specify the type of r.p.)

GIVEN g A x **1 mol A / *PT* g A** x ***CE* mol B / *CE* mol A** x **(6.02×10^{23}) r.p. B / 1 mol B**

"PARTICLE – MASS": (specify the type of r.p.)

GIVEN r.p. A x **1 mol A / (6.02×10^{23}) r.p. A** x ***CE* mol B / *CE* mol A** x ***PT* g B / 1 mol B**

PT = periodic table, molar mass ***CE = coefficients***

EXAMPLE 11) How many r.p. of barium sulfate are made from reacting 5.33 g of barium hydroxide with sulfuric acid?

$Ba(OH)_2$ + H_2SO_4 → $BaSO_4$ + H_2O $Ba(OH)_2$ + H_2SO_4 → $BaSO_4$ + 2H_2O

5.33 ~~g $Ba(OH)_2$~~ x 1 ~~mol $Ba(OH)_2$~~ / 171.34 ~~g $Ba(OH)_2$~~ x 1 ~~mol $BaSO_4$~~ / 1 ~~mol $Ba(OH)_2$~~ x 6.02×10^{23} fun $BaSO_4$ / 1 ~~mol $BaSO_4$~~ = **1.87×10^{22} fun $BaSO_4$**

EXAMPLE 12) How many r.p. of NH_3 are produced from reacting 11 g of hydrogen with excess nitrogen?

N_2 + H_2 → NH_3 N_2 + 3H_2 → 2NH_3

11 ~~g H_2~~ x 1 ~~mol H_2~~ / 2.02 ~~g H_2~~ x 2 ~~mol NH_3~~ / 3 ~~mol H_2~~ x 6.02×10^{23} molecules NH_3 / 1 ~~mol NH_3~~ = **2.2×10^{24} molecules NH_3**

VIII. Limiting Reactant (Limiting Reagent)

A. **limiting reactant**—the *reactant present in the smallest quantity*, limiting the amount of product being made

B. **excess reactant**—the *reactant present in a greater quantity* than the limiting reactant; does not limit formation of product

C. examples

EXAMPLE 13) Aluminum metal reacts with chlorine gas to form aluminum chloride.

If 5.40 mol of aluminum and 8.00 mol of chlorine are available…

A) Which is the limiting reactant?
B) Which is the excess reactant?
C) How many moles of product form?
D) How many moles of excess reactant are left over?

$Al + Cl_2 \rightarrow AlCl_3$

2Al	+	3Cl$_2$	→	2AlCl$_3$
5.40 mol		8.00 mol		
(HAVE)		(HAVE)		

$$5.40\ \cancel{mol\ Al} \times \frac{3\ mol\ Cl_2}{2\ \cancel{mol\ Al}} = 8.10\ mol\ Cl_2 \textit{ needed} \ldots$$

8.10 mol Cl_2 are needed to react with 5.40 mol Al. There are only 8.00 mol Cl_2 available.

A) Cl_2 is the limiting reactant.

If Cl_2 is limiting, Al is in excess. Confirm this by showing all work.

$$8.00\ \cancel{mol\ Cl_2} \times \frac{2\ mol\ Al}{3\ \cancel{mol\ Cl_2}} = 5.33\ mol\ Al \textit{ needed}$$

B) Al is the excess reactant.

C) *** *Use the limiting reactant to find the product, since that is the chemical limiting the yield.*

$$8.00\ \cancel{mol\ Cl_2} \times \frac{2\ mol\ AlCl_3}{3\ \cancel{mol\ Cl_2}} = \boxed{5.33\ mol\ AlCl_3}$$

D) *Remaining excess reactant = (given – used)* 5.40 – 5.33 mol Al = 0.07 mol Al

EXAMPLE 14) Use the equation $H_4B_6O_{11} + H_2O \rightarrow H_3BO_3$

If 35.00 g of $H_4B_6O_{11}$ and 35.00 g of H_2O are available…

A) Which is the limiting reactant?
B) Which is the excess reactant?
C) How many grams of product form?
D) How many grams of excess reactant are left over?

$H_4B_6O_{11} + H_2O \rightarrow H_3BO_3$

$H_4B_6O_{11}$	+	7 H_2O	→	6 H_3BO_3
35.00 g		35.00 g		
(HAVE)		(HAVE)		

$$35.00\ \cancel{g\ H_4B_6O_{11}} \times \frac{1\ \cancel{mol\ H_4B_6O_{11}}}{244.90\ \cancel{g\ H_4B_6O_{11}}} \times \frac{7\ \cancel{mol\ H_2O}}{1\ \cancel{mol\ H_4B_6O_{11}}} \times \frac{18.02\ g\ H_2O}{1\ \cancel{mol\ H_2O}} = 18.03\ g\ H_2O \textit{ needed}$$

18.03 g H_2O are needed to react with 35.00 g $H_4B_6O_{11}$. There are 35.00 g H_2O available.

B) H_2O is the excess reactant.

If H_2O is in excess, $H_4B_6O_{11}$ must be limiting. Confirm this by showing all work.

$$35.00\ \text{g } H_2O \times \frac{1\ \text{mol } H_2O}{18.02\ \text{g } H_2O} \times \frac{1\ \text{mol } H_4B_6O_{11}}{7\ \text{mol } H_2O} \times \frac{244.90\ \text{g } H_4B_6O_{11}}{1\ \text{mol } H_4B_6O_{11}} = 67.95\ \text{g } H_4B_6O_{11}\ \textit{needed}$$

A) $H_4B_6O_{11}$ is the limiting reactant.

C) *** *Use the limiting reactant to find the product, since that is the chemical limiting the yield.*

$$35.00\ \text{g } H_4B_6O_{11} \times \frac{1\ \text{mol } H_4B_6O_{11}}{244.90\ \text{g } H_4B_6O_{11}} \times \frac{6\ \text{mol } H_3BO_3}{1\ \text{mol } H_4B_6O_{11}} \times \frac{61.83\ \text{g } H_3BO_3}{1\ \text{mol } H_3BO_3} = \boxed{53.02\ \text{g } H_3BO_3}$$

D) *Remaining excess reactant = (given – used)* 35.00 – 18.03 g H_2O = $\boxed{16.97\ \text{g } H_2O}$

IX. Percent Yield

A. **percent yield**—*percentage of product recovered*; comparison of actual and theoretical yields

B. **actual yield**—*amount of product obtained in lab*

C. **theoretical yield**—*amount of product predicted by the math (theory)*

$$\textbf{\% YIELD} = \frac{\textbf{ACTUAL YIELD}}{\textbf{THEORETICAL YIELD}} \times \textbf{100}$$

D. examples

EXAMPLE 15) 35.0 g of product should be recovered from an experiment. A student collects 22.9 g at the end of the lab. What is the percent yield?

$$\frac{22.9\ \text{g}}{35.0\ \text{g}} \times 100 = \boxed{65.4\%}$$

EXAMPLE 16) What is the percent yield if 2.89 g of sodium chloride is produced when 1.99 g of hydrochloric acid reacts with excess sodium hydroxide?

$HCl + NaOH \rightarrow NaCl + H_2O$ *Percent yield implies product yield.*

Actual yield = 2.89 g NaCl

Theoretical yield = ?

$$1.99\ \text{g HCl} \times \frac{1\ \text{mol HCl}}{36.46\ \text{g HCl}} \times \frac{1\ \text{mol NaCl}}{1\ \text{mol HCl}} \times \frac{58.44\ \text{g NaCl}}{1\ \text{mol NaCl}} = 3.19\ \text{g NaCl}$$ theoretical yield

$$\text{\% YIELD} = \frac{\text{ACTUAL YIELD}}{\text{THEORETICAL YIELD}} \times 100 = \frac{2.89\ \text{g NaCl}}{3.19\ \text{g NaCl}} = \boxed{90.6\%}$$

*** Summary of Stoich Dimensional Analysis (DA) Calculations ***

ONE STEP DA:		
Mole-mole:	mol A → mol B	
TWO STEP DA:		
Mole-mass	mol A → g B	molar masses to 0.01 g
Mass-mole	g A → mol B	molar masses to 0.01 g
Mole-particle	mol A → r.p. B	specify type of r.p.
Particle-mole	r.p. A → mol B	specify type of r.p.
Mole-volume	mol A → L B	gases at STP
Volume-mole	L A → mol B	gases at STP
THREE STEP DA:		
Mass-mass	g A → g B	molar masses to 0.01 g
Volume-volume	L A → L B	gases at STP
Particle-particle	r.p. A → r.p. B	specify type of r.p.
Mass-Particle	g A → r.p. B	molar masses to 0.01 g; specify type of r.p.
Particle-Mass	r.p. A→ g B	specify type of r.p.; molar masses to 0.01 g
Volume-Particle	L A → r.p. B	gases at STP; specify type of r.p
Particle-Volume	r.p. A → L B	specify type of r.p; gases at STP
Mass-Volume	g A → L B	molar masses to 0.01 g; gases at STP
Volume-Mass	L A → g B	gases at STP; molar masses to 0.01 g