Chem. I Notes – Ch. 11 – STOICHIOMETRY

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

11.1 notes

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 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(1.0) = 4.0 g	2(16.0) = 32.0 g	=	2(18.0) = 36.0 g
L (STP)	2(22.4) = 44.8 L	22.4 L		2(22.4) = 44.8 L

11.2 notes – stoich calculations

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

 # = coefficients

F. examples

E1) How many moles of carbon monoxide are produced when carbon reacts with 0.750 mol of oxygen?

Unbalanced: $C + O_2 \rightarrow CO$ Balanced: $\underline{2}C + O_2 \rightarrow \underline{2}CO$

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

E2) 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.

$Al + O_2 \rightarrow Al_2O_3$ $\underline{4}Al + \underline{3}O_2 \rightarrow \underline{2}Al_2O_3$

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

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

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": GIVEN g A x $\frac{\text{1 mol A}}{\textit{PT}\text{ g A}}$ x $\frac{\textit{CE}\text{ mol B}}{\textit{CE}\text{ mol A}}$ x $\frac{\textit{PT}\text{ g B}}{\text{1 mol B}}$

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

C. examples

E3) How many grams of hydrochloric acid are made from the reaction of 0.500 g of hydrogen gas with excess chlorine gas?

$H_2 + Cl_2 \rightarrow HCl$ $H_2 + Cl_2 \rightarrow \underline{2}HCl$

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

$$0.500\ \cancel{\text{g } H_2} \times \frac{1\ \cancel{\text{mol } H_2}}{2.0\ \cancel{\text{g } H_2}} \times \frac{2\ \cancel{\text{mol HCl}}}{1\ \cancel{\text{mol } H_2}} \times \frac{36.5\text{ g HCl}}{1\ \cancel{\text{mol HCl}}} = \boxed{18\text{ g HCl}}$$

E4) Calculate the numbers of grams of products formed when 25.0 g of sodium nitrate decomposes into sodium nitrite and oxygen.

$NaNO_3 \rightarrow NaNO_2 + O_2$ $\underline{2}NaNO_3 \rightarrow \underline{2}NaNO_2 + O_2$

$$25.0\ \cancel{\text{g } NaNO_3} \times \frac{1\ \cancel{\text{mol } NaNO_3}}{85.0\ \cancel{\text{g } NaNO_3}} \times \frac{2\ \cancel{\text{mol } NaNO_2}}{2\ \cancel{\text{mol } NaNO_3}} \times \frac{69.0\text{ g } NaNO_2}{1\ \cancel{\text{mol } NaNO_2}} = \boxed{20.3\text{ g } NaNO_2}$$

$$25.0\ \cancel{\text{g } NaNO_3} \times \frac{1\ \cancel{\text{mol } NaNO_3}}{85.0\ \cancel{\text{g } NaNO_3}} \times \frac{1\ \cancel{\text{mol } O_2}}{2\ \cancel{\text{mol } NaNO_3}} \times \frac{32.0\text{ g } O_2}{1\ \cancel{\text{mol } O_2}} = \boxed{4.71\text{ g } O_2}$$

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

"MASS – MOLE":

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

"MOLE – MASS":

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

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

E5) How many g of water are produced from the complete combustion of 0.6829 mol of C_2H_2?

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

$$0.6829\ \cancel{\text{mol } C_2H_2} \times \frac{2\ \cancel{\text{mol } H_2O}}{2\ \cancel{\text{mol } C_2H_2}} \times \frac{18.0\text{ g } H_2O}{1\ \cancel{\text{mol } H_2O}} = \boxed{12.3\text{ g } H_2O}$$

E6) 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?

$$56.09\ \cancel{\text{g } CO_2} \times \frac{1\ \cancel{\text{mol } CO_2}}{44.0\ \cancel{\text{g } CO_2}} \times \frac{5\text{ mol } O_2}{4\ \cancel{\text{mol } CO_2}} = \boxed{1.59\text{ mol } O_2}$$

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

Using molar volume in stoich problems

"MASS – VOLUME": (gases @ STP)

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

"VOLUME – MASS": (gases @ STP)

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

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

E7) How many L of hydrogen are produced from the decomposition of 3.50 g of water at STP?

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

$$3.50\ \cancel{\text{g } H_2O} \times \frac{1\ \cancel{\text{mol } H_2O}}{18.0\ \cancel{\text{g } H_2O}} \times \frac{2\ \cancel{\text{mol } H_2}}{2\ \cancel{\text{mol } H_2O}} \times \frac{22.4\text{ L } H_2}{1\ \cancel{\text{mol } H_2}} = \boxed{4.36\text{ L } H_2}$$

E8) 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?

$$5.02\ \cancel{\text{g } C_2H_2} \times \frac{1\ \cancel{\text{mol } C_2H_2}}{26.0\ \cancel{\text{g } C_2H_2}} \times \frac{5\ \cancel{\text{mol } O_2}}{2\ \cancel{\text{mol } C_2H_2}} \times \frac{22.4\text{ L } O_2}{1\ \cancel{\text{mol } O_2}} = \boxed{10.8\text{ L } O_2}$$

VI. **VOLUME-VOLUME Conversions**

"VOLUME – VOLUME": (gases @ STP)

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

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

E9) How many liters of carbon dioxide are produced from 0.252 L of hydrochloric acid reacting with sodium bicarbonate?

$NaHCO_3 + HCl \rightarrow NaCl + CO_2 + H_2O$

$$0.252 \text{ L HCl} \times \frac{1 \text{ mol HCl}}{22.4 \text{ L HCl}} \times \frac{1 \text{ mol } CO_2}{1 \text{ mol HCl}} \times \frac{22.4 \text{ L } CO_2}{1 \text{ mol } CO_2} = \boxed{0.252 \text{ L } CO_2}$$

SHORTCUT: coefficients = 1 mol HCl to 1 mol CO_2, so 0.252 L HCl = $\boxed{0.252 \text{ L } CO_2}$

E10) How many L of sulfur trioxide are produced from the reaction of 36.1 L of oxygen with sulfur dioxide at STP?

$SO_2 + O_2 \rightarrow SO_3$ $\qquad$ $\underline{2}SO_2 + O_2 \rightarrow \underline{2}SO_3$

$$36.1 \text{ L } O_2 \times \frac{1 \text{ mol } O_2}{22.4 \text{ L } O_2} \times \frac{2 \text{ mol } SO_3}{1 \text{ mol } O_2} \times \frac{22.4 \text{ L } SO_3}{1 \text{ mol } SO_3} = \boxed{72.2 \text{ L } SO_3}$$

SHORTCUT: coefficient of O_2 = 1; coefficient of SO_3 = 2 $\qquad$ 36.1 L x 2 = $\boxed{72.2 \text{ L } SO_3}$

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

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

$$\text{GIVEN g A} \times \frac{1 \text{ mol A}}{PT \text{ g A}} \times \frac{CE \text{ mol B}}{CE \text{ mol A}} \times \frac{(6.02 \times 10^{23}) \text{ r.p. B}}{1 \text{ mol B}}$$

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

$$\text{GIVEN r.p. A} \times \frac{1 \text{ mol A}}{(6.02 \times 10^{23}) \text{ r.p. A}} \times \frac{CE \text{ mol B}}{CE \text{ mol A}} \times \frac{PT \text{ g B}}{1 \text{ mol B}}$$

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

E11) How many r.p. of barium sulfate are made from reacting 5.33 g of barium hydroxide with sulfuric acid?

$Ba(OH)_2 + H_2SO_4 \rightarrow BaSO_4 + H_2O$ $\qquad$ $Ba(OH)_2 + H_2SO_4 \rightarrow BaSO_4 + \underline{2}H_2O$

$$5.33 \text{ g } Ba(OH)_2 \times \frac{1 \text{ mol } Ba(OH)_2}{171.3 \text{ g } Ba(OH)_2} \times \frac{1 \text{ mol } BaSO_4}{1 \text{ mol } Ba(OH)_2} \times \frac{6.02 \times 10^{23} \text{ fun. } BaSO_4}{1 \text{ mol } BaSO_4} = \boxed{1.87 \times 10^{22}} \text{ fun. } BaSO_4$$

E12) How many r.p. of NH_3 are produced from reacting 2.07 g of hydrogen with excess nitrogen?

$N_2 + H_2 \rightarrow NH_3$ $\qquad$ $N_2 + \underline{3}H_2 \rightarrow \underline{2}NH_3$

$$2.07 \text{ g } H_2 \times \frac{1 \text{ mol } H_2}{2.0 \text{ g } H_2} \times \frac{2 \text{ mol } NH_3}{3 \text{ mol } H_2} \times \frac{6.02 \times 10^{23} \text{ molecules } NH_3}{1 \text{ mol } NH_3} = \boxed{4.2 \times 10^{23} \text{ molecules } NH_3}$$

11.3 notes

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. example

E13) 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? C) How many moles of product form?

B) Which is the excess reactant? D) How many moles of excess reactant are left over?

$Al + Cl_2 \rightarrow AlCl_3$

$\underline{2}Al + \underline{3}Cl_2 \rightarrow \underline{2}AlCl_3$

5.40 mol 8.00 mol

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

This is the amount of Cl_2 needed to react with 5.40 mol Al. There are only 8.00 mol available.

A) $\boxed{Cl_2 \text{ is the limiting reagent}}$. If Cl_2 is limiting, Al must be in excess. Check it anyway.

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

B) $\boxed{\text{Al is the excess reagent.}}$

C) *Use the limiting reagent 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 reagent = (given – used)* 5.40 – 5.33 mol Al = $\boxed{0.07\ mol\ Al}$

11.4 notes

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

E14) 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?

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

E15) 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 = ?

$$1.99\ \cancel{\text{g HCl}} \times \frac{1\ \cancel{\text{mol HCl}}}{36.5\ \cancel{\text{g HCl}}} \times \frac{1\ \cancel{\text{mol NaCl}}}{1\ \cancel{\text{mol HCl}}} \times \frac{58.5\ \text{g NaCl}}{1\ \cancel{\text{mol NaCl}}} = 3.19\ \text{g NaCl}\quad \text{theoretical yield}$$

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