Chem. I Notes – Ch. 12, part 2 – Using Moles

NOTE: Vocabulary terms are in **<u>boldface and underlined</u>**. Supporting details are in *italics.*

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

CONVERSION FACTOR SUMMARY:

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

<u>stoichiometry</u>—using balanced chemical equations to obtain info.

I. **<u>Mole - Mole (MOL – MOL) Conversions</u>**

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

MOL – MOL :	$\frac{\#\ \text{mol A}}{\#\ \text{mol B}}$	$\frac{\#\ \text{mol B}}{\#\ \text{mol A}}$	**# = *coefficients***

F. examples

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

$C + O_2 \rightarrow CO$ $\qquad$ $2C + O_2 \rightarrow 2CO$

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

E2) Find the number of moles of the reactants, given 0.661 mol of product is formed.

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

$$0.661\ \cancel{mol\ Al_2O_3} \times \frac{4\ mol\ Al}{2\ \cancel{mol Al_2O_3}} = \boxed{1.32\ mol\ Al} \qquad 0.661\ \cancel{mol\ Al_2O_3} \times \frac{3\ mol\ O_2}{2\ \cancel{mol Al_2O_3}} = \boxed{0.992\ mol\ O_2}$$

II. **<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": $$\text{GIVEN g A} \times \frac{\text{1 mol A}}{PT\text{ g A}} \times \frac{CE\text{ mol B}}{CE\text{ mol A}} \times \frac{PT\text{ g B}}{\text{1 mol B}}$$

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?

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

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.

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

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

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

III. Other Stoich Calculations

A. **"mole – mass" (mass – mole) calculations**

"MASS – MOLE":

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

"MOLE – MASS":

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

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?

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

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

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?

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

B. **<u>"mass – volume" (volume – mass) calculations</u> – Using molar volume in stoich problems**

"MASS – VOLUME": (gases @ STP)

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

"VOLUME – MASS": (gases @ STP)

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

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?

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

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

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 water vapor are produced when 5.02 g of C_2H_2 undergoes complete combustion under STP conditions?

$$5.02\ \cancel{\text{g } C_2H_2} \times \frac{1\ \cancel{\text{mol } C_2H_2}}{26.0\ \cancel{\text{g } C_2H_2}} \times \frac{2\ \cancel{\text{mol } H_2O}}{2\ \cancel{\text{mol } C_2H_2}} \times \frac{22.4\text{ L } H_2O}{1\ \cancel{\text{mol } H_2O}} = \boxed{4.32\text{ L } H_2O}$$

C. **<u>"volume – volume" calculations</u>**

"VOLUME – VOLUME": (gases @ STP)

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

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

E9) How many liters of CO_2 are produced from 0.252 L of HCl reacting with $NaHCO_3$?
Use the equation $NaHCO_3 + HCl \rightarrow NaCl + CO_2 + H_2O$

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

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

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

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

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

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

D. **"mass – particle" (particle – mass) calculations**

"MASS – PARTICLE":

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

"PARTICLE – MASS":

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

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

E11) How many formula units of barium sulfate are made from reacting 5.33 g of barium hydroxide with sulfuric acid?

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

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

E12) How many molecules of NH_3 are produced from reacting 2.07 g of H_2 with excess N_2?

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

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

IV. 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?

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

E15) What is the percent yield if 2.89 g of NaCl is produced when 1.99 g of HCl reacts with excess NaOH? Water is the other product.

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

Actual yield = 2.89 g NaCl
Theoretical yield = ?

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

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

Ideal Gas Law will be covered later

Percent Composition already covered in part 1

V. Empirical Formula – Determining Chemical Formulas

A. **<u>Empirical Formula</u>**—*the simplest whole-number ratio of elements in a cmpd.*

B. it is a non-reducible ration of moles

C. problem procedure

> 1. *convert % to grams directly*
> 2. *find numbers of moles*
> 3. *make mole ratios using the smallest mole number as the denominator*
> 4. *use these whole number ratios as the subscripts of the formula*
>
> *(If a number with 0.5 is observed, multiply everything by 2. Don't round up!)*

D. examples

E16) Calculate the empirical formula of a compound composed of 67.6% mercury, 10.8% sulfur, and 21.6% oxygen. *(check the PROBLEM PROCEDURE steps)*

STEP 1… mercury: 67.6% Hg = 67.6 g Hg out of 100 g cmpd.
sulfur: 10.8% S = 10.8 g S out of 100 g cmpd.
oxygen: 21.6% O = 21.6 g C out of 100 g cmpd.

STEP 2... Hg: $67.6 \text{ g C} \times \frac{1 \text{ mol Hg}}{200.6 \text{ g Hg}} = \mathit{0.337\ mol\ Hg}$ S: $10.8 \text{ g S} \times \frac{1 \text{ mol S}}{32.1 \text{ g S}} = \mathit{0.336\ mol\ S}$

O: $21.6 \text{ g O} \times \frac{1 \text{ mol O}}{16.0 \text{ g}} = \mathit{1.35\ mol\ O}$

STEP 3… Hg $= \frac{0.337}{0.336} = 1$ S $= \frac{0.336}{0.336} = 1$ O $= \frac{1.35 \text{ mol}}{0.336 \text{ mol}} = 4$

STEP 4… $Hg_1S_1O_4$ = $\boxed{HgSO_4}$

E17) What is the empirical formula of a compound with 25.9% nitrogen and 74.1% oxygen?

25.9% N = 25.9 g N out of 100 g cmpd. 74.1% O = 74.1 g O out of 100 g cmpd.

N: $25.9 \text{ g N} \times \frac{1 \text{ mol N}}{14.0 \text{ g N}} = \mathit{1.85\ mol\ N}$ O: $74.1 \text{ g O} \times \frac{1 \text{ mol O}}{16.0 \text{ g O}} = \mathit{4.63\ mol\ O}$

N: $\frac{1.85}{1.85} = 1$ O: $\frac{4.63}{1.85} = 2.5$ $N_1O_{2.5}$ – can't have .5 subscripts x 2 = $\boxed{N_2O_5}$

VI. **Molecular Formula**

A. *a multiple of the empirical formula*
B. still whole number ratios
C. examples

E18) A compound with an empirical formula of CH has a molecular weight of 78.0 g/mol. What is the molecular formula?

molar mass of CH = 12.0 + 1.0 = 13.0 g   78 / 13 = 6   molecular formula = $\boxed{C_6H_6}$

E19) A compound is 75.46% carbon, 4.43% hydrogen, and 20.10% oxygen by mass. It has a molecular mass of 318.31 g/mol. What is the molecular formula for this compound?

67.6% C = 75.46 g C out of 100 g cmpd.   4.43% H = 4.43 g H out of 100 g cmpd.
20.10% O = 20.10 g O out of 100 g cmpd.

(75.46 g C) (1 mol/ 12.0 g C) = *6.29 mol C*   (4.43 g H) (1 mol/ 1.0 g H) = *4.4 mol H*
(20.10 g O) (1 mol/ 16.0 g O) = *1.26 mol O*

(6.29 mol C)/ (1.26) = 4.99 = 5 mol C
(4.4 mol H)/ (1.26) = 3.49 = 3.5 mol H
(1.26 mol O)/ (1.26) = 1 mol O

.5 value means multiply subscripts by 2:   empirical fmla. = $C_{10}H_7O_2$

Now that you have the emp.fmla., you can find the molecular fmla like in problem E18.
emp. fmla. mass = 10(12.0) + 7(1.0) + 2(16.0) = 159.1 g/mol
The problem says the molecular mass is 318.31 g per mole.

$\frac{318.31 \text{ g/mol}}{159.1 \text{ g/mol}} = 2.001 = 2$ ratio

Since there are two empirical units in a molecular unit, the molecular formula = $\boxed{C_{20}H_{14}O_4}$