

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).

	<u>2</u> H ₂ (g)	+	<u>1</u> O ₂ (g)	→	<u>2</u> H ₂ O (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

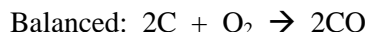
II. **Mole - Mole (MOL – MOL) Conversions**

- 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 : # mol B (new, ending substance – what is being asked for)
mol A (old, starting substance – what is given originally)
 # = *coefficients*

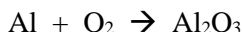
F. examples

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



$$0.750 \text{ mol } \cancel{\text{O}_2} \times \frac{2 \text{ mol CO}}{1 \text{ mol } \cancel{\text{O}_2}} = \boxed{1.50 \text{ mol CO}}$$

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.



$$0.661 \text{ mol } \cancel{\text{Al}_2\text{O}_3} \times \frac{4 \text{ mol Al}}{2 \text{ mol } \cancel{\text{Al}_2\text{O}_3}} = \boxed{1.32 \text{ mol Al}}$$

$$0.661 \text{ mol } \cancel{\text{Al}_2\text{O}_3} \times \frac{3 \text{ mol O}_2}{2 \text{ mol } \cancel{\text{Al}_2\text{O}_3}} = \boxed{0.992 \text{ mol O}_2}$$

III. MASS – MASS Conversions – 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

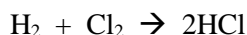
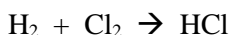
“MASS – MASS”: $\text{GIVEN g A} \times \frac{1 \text{ mol A}}{\text{PT g A}} \times \frac{\text{CE mol B}}{\text{CE mol A}} \times \frac{\text{PT g B}}{1 \text{ mol B}}$

PT = periodic table, molar mass

CE = coefficients

C. examples

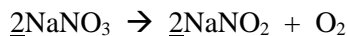
EXAMPLE 3) How many grams of hydrochloric acid are made from the reaction of 0.500 g of hydrogen gas with excess chlorine gas?



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

$$0.500 \text{ g } \cancel{\text{H}_2} \times \frac{1 \text{ mol } \cancel{\text{H}_2}}{2.02 \text{ g } \cancel{\text{H}_2}} \times \frac{2 \text{ mol HCl}}{1 \text{ mol } \cancel{\text{H}_2}} \times \frac{36.46 \text{ g HCl}}{1 \text{ mol HCl}} = \boxed{18.0 \text{ g HCl}}$$

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



$$25.0 \text{ g } \cancel{\text{NaNO}_3} \times \frac{1 \text{ mol } \cancel{\text{NaNO}_3}}{84.99 \text{ g } \cancel{\text{NaNO}_3}} \times \frac{2 \text{ mol NaNO}_2}{2 \text{ mol } \cancel{\text{NaNO}_3}} \times \frac{69.00 \text{ g NaNO}_2}{1 \text{ mol NaNO}_2} = \boxed{20.3 \text{ g NaNO}_2}$$

$$25.0 \text{ g } \cancel{\text{NaNO}_3} \times \frac{1 \text{ mol } \cancel{\text{NaNO}_3}}{84.99 \text{ g } \cancel{\text{NaNO}_3}} \times \frac{1 \text{ mol O}_2}{2 \text{ mol } \cancel{\text{NaNO}_3}} \times \frac{32.00 \text{ g O}_2}{1 \text{ mol O}_2} = \boxed{4.71 \text{ g O}_2}$$

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

“MASS – MOLE”:

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

“MOLE – MASS”:

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

PT = periodic table, molar mass CE = coefficients

EXAMPLE 5) How many g of water are produced from the complete combustion of C₂H₂?



$$0.6829 \text{ mol C}_2\text{H}_2 \times \frac{2 \text{ mol H}_2\text{O}}{2 \text{ mol C}_2\text{H}_2} \times \frac{18.02 \text{ g H}_2\text{O}}{1 \text{ mol H}_2\text{O}} = 12.31 \text{ g H}_2\text{O}$$

EXAMPLE 6) Using the equation $2\text{C}_2\text{H}_2 + 5\text{O}_2 \rightarrow 4\text{CO}_2 + 2\text{H}_2\text{O}$ how many moles of O₂ would be needed to produce 56.09 g of CO₂?

$$56.09 \text{ g CO}_2 \times \frac{1 \text{ mol CO}_2}{44.01 \text{ g CO}_2} \times \frac{5 \text{ mol O}_2}{4 \text{ mol CO}_2} = 1.593 \text{ mol O}_2$$

V. MASS-VOLUME (or VOLUME – MASS) Conversions - Using molar volume in stoich problems

“MASS – VOLUME”: (gases @ STP)

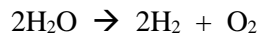
$$\frac{\text{GIVEN g A}}{PT \text{ g A}} \times \frac{1 \text{ mol A}}{CE \text{ mol A}} \times \frac{CE \text{ mol B}}{CE \text{ mol A}} \times \frac{22.4 \text{ L B}}{1 \text{ mol B}}$$

“VOLUME – MASS”: (gases @ STP)

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

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?



$$3.50 \text{ g H}_2\text{O} \times \frac{1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} \times \frac{1 \text{ mol O}_2}{2 \text{ mol H}_2\text{O}} \times \frac{22.4 \text{ L O}_2}{1 \text{ mol O}_2} = 2.17 \text{ L O}_2$$

EXAMPLE 8) Using the equation $2\text{C}_2\text{H}_2 + 5\text{O}_2 \rightarrow 4\text{CO}_2 + 2\text{H}_2\text{O}$, how many liters of oxygen gas are needed when 5.02 g of C₂H₂ undergoes complete combustion under STP conditions?

$$5.02 \text{ g C}_2\text{H}_2 \times \frac{1 \text{ mol C}_2\text{H}_2}{26.04 \text{ g C}_2\text{H}_2} \times \frac{5 \text{ mol O}_2}{2 \text{ mol C}_2\text{H}_2} \times \frac{22.4 \text{ L O}_2}{1 \text{ mol O}_2} = 10.8 \text{ L O}_2$$

VI. VOLUME-VOLUME Conversions

“VOLUME – VOLUME”: (gases @ STP)

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

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?



$$0.252 \text{ L HCl} \times \frac{1 \text{ mol HCl}}{22.4 \text{ L HCl}} \times \frac{1 \text{ mol CO}_2}{1 \text{ mol HCl}} \times \frac{22.4 \text{ L CO}_2}{1 \text{ mol CO}_2} = 0.252 \text{ L CO}_2$$

SHORTCUT: coefficients = 1 mol HCl to 1 mol CO₂, so 0.252 L HCl = 0.252 L CO₂

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



$$36.1 \text{ L O}_2 \times \frac{1 \text{ mol O}_2}{22.4 \text{ L O}_2} \times \frac{2 \text{ mol SO}_3}{1 \text{ mol O}_2} \times \frac{22.4 \text{ L SO}_3}{1 \text{ mol SO}_3} = 72.2 \text{ L SO}_3$$

SHORTCUT: coefficient of O₂ = 1; coefficient of SO₃ = 2 36.1 L x 2 = 72.2 L SO₃

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

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

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

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

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

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?



$$5.33 \text{ g Ba(OH)}_2 \times \frac{1 \text{ mol Ba(OH)}_2}{171.34 \text{ g Ba(OH)}_2} \times \frac{1 \text{ mol BaSO}_4}{1 \text{ mol Ba(OH)}_2} \times \frac{6.02 \times 10^{23} \text{ fun BaSO}_4}{1 \text{ mol BaSO}_4} = 1.87 \times 10^{22} \text{ fun BaSO}_4$$

EXAMPLE 12) How many r.p. of NH₃ are produced from reacting 11 g of hydrogen with excess nitrogen?



$$11 \text{ g H}_2 \times \frac{1 \text{ mol H}_2}{2.02 \text{ g H}_2} \times \frac{2 \text{ mol NH}_3}{3 \text{ mol H}_2} \times \frac{6.02 \times 10^{23} \text{ molecules NH}_3}{1 \text{ mol NH}_3} = 2.2 \times 10^{24} \text{ molecules NH}_3$$

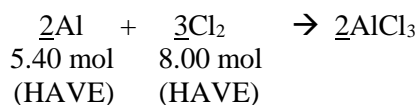
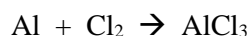
VIII. Limiting Reactant (Limiting Reagent)

- 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?



$$5.40 \text{ mol Al} \times \frac{3 \text{ mol Cl}_2}{2 \text{ mol Al}} = 8.10 \text{ mol Cl}_2 \text{ needed ...}$$

8.10 mol Cl₂ are needed to react with 5.40 mol Al. There are only 8.00 mol Cl₂ available.

- A) Cl₂ is the limiting reactant.

If Cl₂ is limiting, Al is in excess. Confirm this by showing all work.

$$8.00 \text{ mol Cl}_2 \times \frac{2 \text{ mol Al}}{3 \text{ mol Cl}_2} = 5.33 \text{ mol Al needed}$$

- B) Al is the excess reactant.

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

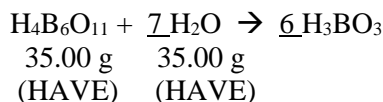
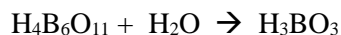
$$8.00 \text{ mol Cl}_2 \times \frac{2 \text{ mol AlCl}_3}{3 \text{ mol Cl}_2} = \boxed{5.33 \text{ mol AlCl}_3}$$

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

EXAMPLE 14) Use the equation $\text{H}_4\text{B}_6\text{O}_{11} + \text{H}_2\text{O} \rightarrow \text{H}_3\text{BO}_3$

If 35.00 g of H₄B₆O₁₁ and 35.00 g of H₂O 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?



$$35.00 \text{ g H}_4\text{B}_6\text{O}_{11} \times \frac{1 \text{ mol H}_4\text{B}_6\text{O}_{11}}{244.90 \text{ g H}_4\text{B}_6\text{O}_{11}} \times \frac{7 \text{ mol H}_2\text{O}}{1 \text{ mol H}_4\text{B}_6\text{O}_{11}} \times \frac{18.02 \text{ g H}_2\text{O}}{1 \text{ mol H}_2\text{O}} = 18.03 \text{ g H}_2\text{O needed}$$

18.03 g H₂O are needed to react with 35.00 g H₄B₆O₁₁. There are 35.00 g H₂O available.

B) H_2O is the excess reactant.

If H_2O is in excess, $\text{H}_4\text{B}_6\text{O}_{11}$ must be limiting. Confirm this by showing all work.

$$35.00 \text{ g H}_2\text{O} \times \frac{1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} \times \frac{1 \text{ mol H}_4\text{B}_6\text{O}_{11}}{7 \text{ mol H}_2\text{O}} \times \frac{244.90 \text{ g H}_4\text{B}_6\text{O}_{11}}{1 \text{ mol H}_4\text{B}_6\text{O}_{11}} = 67.95 \text{ g H}_4\text{B}_6\text{O}_{11} \text{ needed}$$

A) $\text{H}_4\text{B}_6\text{O}_{11}$ is the limiting reactant.

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

$$35.00 \text{ g H}_4\text{B}_6\text{O}_{11} \times \frac{1 \text{ mol H}_4\text{B}_6\text{O}_{11}}{244.90 \text{ g H}_4\text{B}_6\text{O}_{11}} \times \frac{6 \text{ mol H}_3\text{BO}_3}{1 \text{ mol H}_4\text{B}_6\text{O}_{11}} \times \frac{61.83 \text{ g H}_3\text{BO}_3}{1 \text{ mol H}_3\text{BO}_3} = 53.02 \text{ g H}_3\text{BO}_3$$

$$\text{D) Remaining excess reactant} = (\text{given} - \text{used}) \quad 35.00 - 18.03 \text{ g H}_2\text{O} = 16.97 \text{ g H}_2\text{O}$$

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)

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

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

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?



Actual yield = 2.89 g NaCl

Theoretical yield = ?

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

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

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

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