Chapter 13 – Stoichiometry

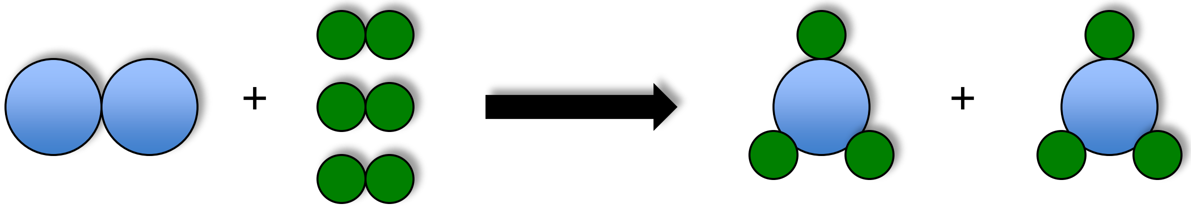
<u>Stoichiometry</u> (STOY-key-OM-etry) problems are based on quantitative relationships between the different substances involved in a chemical reaction.

13.1 Mole Ratio

The coefficients in a balanced equation given the moles of each substance in that equation.
For the combination reaction of hydrogen gas and nitrogen gas to produce ammonia, the coefficients give us valuable information about the reaction:

$$\mathbf{N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g)}$$

For every 1 molecule of nitrogen that reacts, it needs three molecules of hydrogen to react with it. Together, they produce 2 molecules of ammonia, NH_3.



⇒ We can also say for every 1 **mole** of N_2 that reacts, 3 **moles** of H_2 reacts with it to produce 2 **moles** of NH_3.

⇒ **These are mole-to-mole relationships/ratios**.
- Given a balanced equations; *any* two compounds can be compared using mole-to-mole relationships or mole ratios.

$$\mathbf{C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)}$$

The mole ratios would be:

$$\left(\frac{3\text{ mol }CO_2}{5\text{ mol }O_2}\right) \text{ and } \left(\frac{1\text{ mol }C_3H_8}{4\text{ mol }H_2O}\right) \text{ and } \left(\frac{3\text{ mol }CO_2}{4\text{ mol }H_2O}\right) \text{ and}$$

$$\left(\frac{5\text{ mol }O_2}{4\text{ mol }H_2O}\right) \text{ and } \left(\frac{5\text{ mol }O_2}{1\text{ mol }C_3H_8}\right) \text{ and } \left(\frac{3\text{ mol }CO_2}{1\text{ mol }C_3H_8}\right)\text{, etc.}$$

These mole ratios are used to solve problems such as how many moles of carbon dioxide, CO_2, would be produced from 6.25 moles of oxygen gas?

Solution: $6.25\text{ moles }O_2 \left(\frac{3\text{ mol }CO_2}{5\text{ mol }O_2}\right) = 3.75\text{ moles }CO_2$

<u>YouTube Video</u>: [Solving Stoichiometry Problems by weiner7000] STOP at 7:25 until you have read through the next three sections.

13.2 Mass-Mass Stoichiometry

$$\text{Grams of Given} \xrightarrow[\text{Mass}]{\text{Molar}} \text{Moles of Given} \xrightarrow[\text{Ratio}]{\text{Mole-Mole}} \text{Moles of Unknown} \xrightarrow[\text{Mass}]{\text{Molar}} \text{Grams of Unknown}$$

Steps:
1) Grams of given ↔ moles of given (Use the MM of given as your conversion factor.)
2) Moles of given ↔ moles of unknown (Use mole ratios from **balanced** equation.)
3) Moles unknown ↔ grams unknown (Use the MM of unknown as your conversion factor.)

- ➢ Important to include units & formulas for all substances- units cancel except wanted units.

Example: Calculate the mass of H_2 required to react with 8.75 g of O_2 according to the following balanced equations: $O_2(g) + 2\,H_2(g) \rightarrow 2\,H_2O(g)$

Answer: $8.75\text{ g } O_2 \left(\frac{1\text{ mol } O_2}{32.00\text{ g } O_2}\right)\left(\frac{2\text{ mol } H_2}{1\text{ mol } O_2}\right)\left(\frac{2.02\text{ g } H_2}{1\text{ mol } H_2}\right) = \mathbf{1.10\text{ g } H_2}$

(In your calculator: 8.75 ÷ 32.00 × 2 × 2.02 =)

13.3 Mass-Volume Stoichiometry

$$\text{Grams of Given} \xrightarrow[\text{Mass}]{\text{Molar}} \text{Moles of Given} \xrightarrow[\text{Ratio}]{\text{Mole-Mole}} \text{Moles of Unknown} \xrightarrow[\text{Volume } \textit{gas @ STP}]{\text{Molar}} \textbf{Liters} \text{ of Unknown}$$

OR

$$\textbf{Liters} \text{ of Given} \xrightarrow[\text{Volume } \textit{gas @ STP}]{\text{Molar}} \text{Moles of Given} \xrightarrow[\text{Ratio}]{\text{Mole-Mole}} \text{Moles of Unknown} \xrightarrow[\text{Mass}]{\text{Molar}} \text{Mass of Unknown}$$

Recall: Avogadro's Molar Volume is 22.4 L/mol for a <u>gas only</u> at STP

Steps:
1) If given grams, use MM as your conversion factor to get to moles of the given
   -If given volume, use molar volume to get to moles of the given
2) Use mol ratios to convert from moles of given to moles of unknown
3) If asked to find grams, use MM as your conversion factor to get to grams of the unknown
   -If asked to find volume, use molar volume to get to liters of the unknown

Example: How many liters of oxygen gas are needed to react with 0.234 grams of SO_2 gas at STP?

$$\mathbf{2\,SO_2(g) + O_2(g) \rightarrow 2\,SO_3(g)}$$

Answer: $0.234\text{ g } SO_2 \left(\frac{1\text{ mol } SO_2}{64.07\text{ g } SO_2}\right)\left(\frac{1\text{ mol } O_2}{2\text{ mol } SO_2}\right)\left(\frac{22.4\text{ L } O_2}{1\text{ mol } O_2}\right) = \mathbf{0.0409\text{ L } O_2}$

(In your calculator: 0.234 ÷ 64.07 ÷ 2 × 22.4 =)

13.4 Volume-Volume Stoichiometry

Liters of Given $\xrightarrow[\text{Volume gas @ STP}]{\text{Molar}}$ Moles of Given $\xrightarrow[\text{Ratio}]{\text{Mole-Mole}}$ Moles of Unknown $\xrightarrow[\text{Volume gas @ STP}]{\text{Molar}}$ Liters of Unknown

Fact: If you start with liters of the given and are asked to find liters of the unknown, as long as the gases are at the same temperature and pressure the molar volumes will cancel out with each other so you are basically just using the mole ratio to solve this type of problem.

Example: How many liters of oxygen gas are needed to produce 36.5 liters of SO_3 gas at STP?

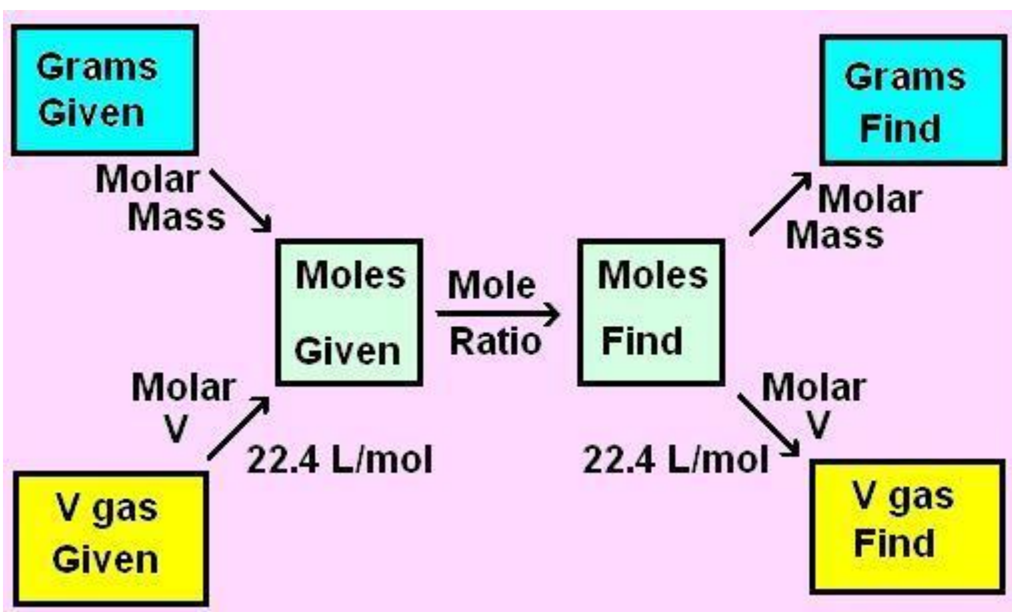
$$2\ SO_2(g) + O_2(g) \rightarrow 2\ SO_3(g)$$

Answer: $36.5\ L\ SO_3 \left(\frac{1\ mol\ SO_3}{22.4\ L\ SO_3}\right)\left(\frac{1\ mol\ O_2}{2\ mol\ SO_3}\right)\left(\frac{22.4\ L\ O_2}{1\ mol\ O_2}\right) = 18.3\ L\ O_2$

(notice molar volume cancels out with itself on this problem)

$36.5\ L\ SO_3 \left(\frac{1\ mol\ O_2}{2\ mol\ SO_3}\right) = \mathbf{18.3\ L\ O_2}$

Putting them all together you get this chart:



YouTube Video: Solving Stoichiometry Problems by weiner7000
CONTIUNUE from 7.25 for more examples

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CHAPTER 13 PRACTICE PROBLEMS

Example 1: $N_2\,(g) \quad + \quad 3\,H_2\,(g) \quad \rightarrow \quad 2\,NH_3\,(g)$

A. How many moles of N_2 are needed to completely react with 6.75 moles of H_2.

B. How many moles of NH_3 form when 3.25 moles of N_2 react?

C. How many moles of H_2 are required to produce 4.50 moles of NH_3?

Example 2: Consider the following reaction to produce iron, Fe (s):

$$Fe_2O_3\,(s) + 3\,CO\,(g) \rightarrow 2\,Fe\,(s) + 3\,CO_2\,(g)$$

A. Calculate the mass of CO needed to react completely with 50.0 g of Fe_2O_3 .

B. Calculate the mass of iron produced when 125 g of CO reacts completely.

C. Calculate the mass of CO_2 produced when 75.0 g of iron is produced.

Example 3: Calculate the volume (in liters) of oxygen gas required to react with 50.0 g of aluminum at STP.

$$4\,Al\,(s) + 3\,O_2\,(g) \xrightarrow{\text{spark}} 2\,Al_2O_3\,(s)$$

Example 4: An automobile airbag inflates when N_2 gas results from the explosive decomposition of sodium azide (NaN_3),

$$2\,NaN_3\,(s) \xrightarrow{\text{spark}} 2\,Na\,(s) + 3\,N_2\,(g)$$

Calculate the mass of NaN_3 required to produce 50.0 L of N_2 gas at STP.

Answers to Practice Problems

Example 1 A $6.75\text{ moles } H_2\left(\frac{1\text{ mol } N_2}{3\text{ mol } H_2}\right) =$ **2.25 mol N_2**

B $3.25\text{ moles } N_2\left(\frac{2\text{ mol } NH_3}{1\text{ mol } N_2}\right) =$ **6.50 mol NH_3**

C $4.50\text{ moles } NH_3\left(\frac{3\text{ mol } H_2}{2\text{ mol } NH_3}\right) =$ **6.75 mol H_2**

Example 2 A $50.0\,g\,Fe_2O_3\left(\frac{1\text{ mole }Fe_2O_3}{159.70\text{ g}Fe_2O_3}\right)\left(\frac{3\text{ mole CO}}{1\text{ mole }Fe_2O_3}\right)\left(\frac{28.01\text{ gCO}}{1\text{ mole CO}}\right)=$ **26.3 g CO**

B $125\text{ g CO}\left(\frac{1\text{ mole CO}}{28.01\text{ gCO}}\right)\left(\frac{2\text{ mole Fe}}{3\text{ mole CO}}\right)\left(\frac{55.85\text{ g Fe}}{1\text{ mole Fe}}\right)=$ **166 g Fe**

C $75.0\text{g Fe}\left(\frac{1\text{ mole Fe}}{55.85\text{ gFe}}\right)\left(\frac{3\text{ mole }CO_2}{2\text{ mole Fe}}\right)\left(\frac{44.01\text{g }CO_2}{1\text{ mole }CO_2}\right)=$ **88.7 g CO_2**

Example 3 $50.0\text{g Al}\left(\frac{1\text{ mole Al}}{26.98\text{ gAl}}\right)\left(\frac{3\text{ mole }O_2}{4\text{ mole Al}}\right)\left(\frac{22.4\text{L }O_2}{1\text{ mole }O_2}\right)=$ **31.1 L O_2**

Example 4 $50.0\text{L}N_2\left(\frac{\text{mol }N_2}{22.4\text{L}N_2}\right)\left(\frac{2\text{mol }NaN_3}{3\text{ mol}N_2}\right)\left(\frac{65.02\text{g }NaN_3}{1\text{mol }NaN_3}\right)=$ **96.8 g NaN_3**