Chapter 13 – Stoichiometry

Stoichiometry (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:

\[
\text{N}_2(g) + 3 \text{H}_2(g) \rightarrow 2 \text{NH}_3(g)
\]

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, \( \text{NH}_3 \).

⇒ We can also say for every 1 mole of \( \text{N}_2 \) that reacts, 3 moles of \( \text{H}_2 \) reacts with it to produce 2 moles of \( \text{NH}_3 \).

⇒ **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.

\[
\text{C}_3\text{H}_8(g) + 5 \text{O}_2(g) \rightarrow 3 \text{CO}_2(g) + 4 \text{H}_2\text{O}(g)
\]

The mole ratios would be:

\[
\left( \frac{3 \text{ mol CO}_2}{5 \text{ mol O}_2} \right) \quad \text{and} \quad \left( \frac{1 \text{ mol C}_3\text{H}_8}{4 \text{ mol H}_2\text{O}} \right) \quad \text{and} \quad \left( \frac{3 \text{ mol CO}_2}{4 \text{ mol H}_2\text{O}} \right) \quad \text{and}
\]

\[
\left( \frac{5 \text{ mol O}_2}{4 \text{ mol H}_2\text{O}} \right) \quad \text{and} \quad \left( \frac{5 \text{ mol O}_2}{1 \text{ mol C}_3\text{H}_8} \right) \quad \text{and} \quad \left( \frac{3 \text{ mol CO}_2}{1 \text{ mol C}_3\text{H}_8} \right), \text{ etc.}
\]

These mole ratios are used to solve problems such as how many moles of carbon dioxide, \( \text{CO}_2 \), would be produced from 6.25 moles of oxygen gas?

Solution: 6.25 moles \( \text{O}_2 \left( \frac{3 \text{ mol CO}_2}{5 \text{ mol O}_2} \right) = 3.75 \) moles \( \text{CO}_2 \)

YouTube Video: [Solving Stoichiometry Problems by weiner7000](https://www.youtube.com/watch?v=weiner7000) STOP at 7:25 until you have read through the next three sections.
13.2 Mass-Mass Stoichiometry

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) → 2 H$_2$O(g)

Answer: $8.75 \text{ g O}_2 \left(\frac{1 \text{ mol O}_2}{32.00 \text{ g O}_2}\right) \left(\frac{2 \text{ mol H}_2}{1 \text{ mol O}_2}\right) \left(\frac{2.02 \text{ g H}_2}{1 \text{ mol H}_2}\right) = 1.10 \text{ g H}_2$

(In your calculator: $8.75 \div 32.00 \times 2 \times 2.02 =$)

13.3 Mass-Volume Stoichiometry

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?

$2 \text{ SO}_2(\text{g}) + \text{ O}_2(\text{g}) \rightarrow 2 \text{ SO}_3(\text{g})$

Answer: $0.234 \text{ g SO}_2 \left(\frac{1 \text{ mol SO}_2}{64.07 \text{ g SO}_2}\right) \left(\frac{1 \text{ mol O}_2}{2 \text{ mol SO}_2}\right) \left(\frac{22.4 \text{ L O}_2}{1 \text{ mol O}_2}\right) = 0.0409 \text{ L O}_2$

(In your calculator: $0.234 \div 64.07 \times 2 \times 22.4 =$)
13.4 Volume-Volume Stoichiometry

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\textsubscript{3} gas at STP?

\[
2 \text{SO}_2(g) + \text{O}_2(g) \rightarrow \frac{3}{2} \text{SO}_3(g)
\]

Answer: \[
36.5 \text{L SO}_3 \left(\frac{1 \text{ mol SO}_3}{22.4 \text{ L SO}_3}\right) \left(\frac{1 \text{ mol O}_2}{2 \text{ mol SO}_3}\right) \left(\frac{22.4 \text{ L O}_2}{1 \text{ mol O}_2}\right) = 18.3 \text{ L O}_2
\]

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

\[
36.5 \text{ L SO}_3 \left(\frac{1 \text{ mol O}_2}{2 \text{ mol SO}_3}\right) = 18.3 \text{ L O}_2
\]

Putting them all together you get this chart:

YouTube Video: [Solving Stoichiometry Problems by weiner7000](http://www.youtube.com/watch?v=7000)

CONTINUE from 7.25 for more examples
CHAPTER 13 PRACTICE PROBLEMS

Example 1: \( \text{N}_2 \text{(g)} + 3 \text{H}_2 \text{(g)} \rightarrow 2 \text{NH}_3 \text{(g)} \)

A. How many moles of \( \text{N}_2 \) are needed to completely react with 6.75 moles of \( \text{H}_2 \). 
B. How many moles of \( \text{NH}_3 \) form when 3.25 moles of \( \text{N}_2 \) react? 
C. How many moles of \( \text{H}_2 \) are required to produce 4.50 moles of \( \text{NH}_3 \)?

Example 2: Consider the following reaction to produce iron, \( \text{Fe} \) (s):

\[ \text{Fe}_2\text{O}_3 \text{(s)} + 3 \text{CO} \text{(g)} \rightarrow 2 \text{Fe} \text{(s)} + 3 \text{CO}_2 \text{(g)} \]

A. Calculate the mass of \( \text{CO} \) needed to react completely with 50.0 g of \( \text{Fe}_2\text{O}_3 \). 
B. Calculate the mass of iron produced when 125 g of \( \text{CO} \) reacts completely. 
C. Calculate the mass of \( \text{CO}_2 \) 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.

\[ 4 \text{Al} \text{(s)} + 3 \text{O}_2 \text{(g)} \rightarrow 2 \text{Al}_2\text{O}_3 \text{(s)} \]

Example 4: An automobile airbag inflates when \( \text{N}_2 \) gas results from the explosive decomposition of sodium azide (\( \text{NaN}_3 \)),

\[ 2 \text{NaN}_3 \text{(s)} \rightarrow 2 \text{Na} \text{(s)} + 3 \text{N}_2 \text{(g)} \]

Calculate the mass of \( \text{NaN}_3 \) required to produce 50.0 L of \( \text{N}_2 \) gas at STP.

Answers to Practice Problems

Example 1
A. \( 6.75 \text{ moles H}_2 \left( \frac{1 \text{ mol N}_2}{3 \text{ mol H}_2} \right) = 2.25 \text{ mol N}_2 \)
B. \( 3.25 \text{ moles N}_2 \left( \frac{2 \text{ mol NH}_3}{1 \text{ mol N}_2} \right) = 6.50 \text{ mol NH}_3 \)
C. \( 4.50 \text{ moles NH}_3 \left( \frac{3 \text{ mol H}_2}{2 \text{ mol NH}_3} \right) = 6.75 \text{ mol H}_2 \)
Example 2  A  $50.0 \text{g Fe}_2\text{O}_3 \left( \frac{1 \text{ mole Fe}_2\text{O}_3}{159.70 \text{ g Fe}_2\text{O}_3} \right) \left( \frac{3 \text{ mole CO}}{1 \text{ mole Fe}_2\text{O}_3} \right) \left( \frac{28.01 \text{ g CO}}{1 \text{ mole CO}} \right) = 26.3 \text{ g CO}$

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

C  $75.0 \text{ g Fe} \left( \frac{1 \text{ mole Fe}}{55.85 \text{ g Fe}} \right) \left( \frac{3 \text{ mole CO}_2}{2 \text{ mole Fe}} \right) \left( \frac{44.01 \text{ g CO}_2}{1 \text{ mole CO}_2} \right) = 88.7 \text{ g CO}_2$

Example 3  $50.0 \text{ g Al} \left( \frac{1 \text{ mole Al}}{26.98 \text{ g Al}} \right) \left( \frac{3 \text{ mole O}_2}{4 \text{ mole Al}} \right) \left( \frac{22.4 \text{ L O}_2}{1 \text{ mole O}_2} \right) = 31.1 \text{ L O}_2$

Example 4  $50.0 \text{ L N}_2 \left( \frac{\text{mol N}_2}{22.4 \text{ L N}_2} \right) \left( \frac{2 \text{ mol NaN}_3}{3 \text{ mol N}_2} \right) \left( \frac{65.02 \text{ g NaN}_3}{1 \text{ mol NaN}_3} \right) = 96.8 \text{ g NaN}_3$