Unit 8
Stoichiometry Notes

- **Stoichiometry** is a big word for a process that chemist’s use to calculate amounts in reactions. It makes use of the coefficient ratio set up by balanced reaction equations to make connections between the **reactants** and **products** in reactions.

- Stoichiometry calculates the quantities of reactants and products in a chemical reaction. **The equation must be balanced!**

- Questions that deal with amounts in reactions are examples of reaction stoichiometry. We already have the tools necessary to solve this question. We just need to learn a new way to apply skills such as **writing chemical formulas, calculating** formula masses, and converting from mass to **moles**, particles to **moles**, and volume of gases to **moles**.

- Mole to Mole Conversions- you must have **the Mole Ratio**.

**Illustration:**
Let’s use an analogy that we can understand to begin to understand the process. The KEY to any mole conversion is the ratio of coefficients in the reaction equation. Say I want to make a bacon double cheeseburger. Let’s get our recipe together.

1 hamburger bun + 2 hamburger patties + 2 slices of cheese + 4 strips of bacon → 1 bacon double cheeseburger

**Based on this recipe:**
1) If I have five bacon double cheeseburgers:
   a. How many hamburger buns did you use? → 5 hamburger bun
   b. How many hamburger patties did you use? → 10 hamburger patties
   c. How many slices of cheese did you use? → 10 slices of cheese
   d. How many strips of bacon did you use? → 20 strips of bacon

2) How many bacon double cheeseburgers can you make if you start with:
   a. 2 buns, 4 patties, 4 slices of cheese, 8 strips of bacon
      2 bacon double cheese burgers
   b. 1 dozen buns, 2 dozen patties, 2 dozen slices of cheese, 4 dozen strips of bacon
      1 dozen bacon double cheese burgers
c. 1 mole of buns, 2 mol of patties, 2 mol of cheese slices, 4 mol of bacon strips

1 mole of bacon double cheese burgers

d. 10 buns, 20 patties, 2 slices of cheese, 40 strips of bacon

1 bacon double cheese burger

To think through these questions we were using the ratios set up by the reaction equation (a.k.a. recipe) We understood that to produce one complete bacon double cheeseburger we needed to have each of the above ingredients in a 1 bun to 2 patties to 2 slices of cheese to 4 slices of bacon. This ratio is called the coefficient ratio. If we want to make 3 sandwiches then we would just triple all of the coefficients.

THIS COEFFICIENT RATIO IS KEY TO DOING STOICHIOMETRY.

Let’s apply the above logic to a chemical recipe (a.k.a. chemical reaction equation).

\[ \text{1 H}_2\text{SO}_4 + 2 \text{NaOH} \rightarrow \text{1 Na}_2\text{SO}_4 + 2 \text{H}_2\text{O} \]

If I use 1 mole of \( \text{H}_2\text{SO}_4 \)

How many moles of sodium hydroxide do I need?

2 moles of \( \text{NaOH} \)

How many moles of sodium sulfate do I make?

1 Mole of \( \text{Na}_2\text{SO}_4 \)

Consider:

- Consider the reaction \( 2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O} \). How many moles of water will be produced if there are 3.5 moles of oxygen?

  pathway: \( \text{mol of O}_2 \rightarrow \text{mol of H}_2\text{O} \)

  \[
  \frac{3.5 \text{ moles O}_2}{1 \text{ moles O}_2} \times \frac{2 \text{ moles H}_2\text{O}}{1 \text{ moles O}_2} = 7.0 \text{ mol H}_2\text{O}
  \]

- Mole to Mass. How many grams of water will be produced if there are 3.5 moles of oxygen?

  pathway: \( \text{mol of O}_2 \rightarrow \text{mol of H}_2\text{O} \rightarrow \text{grams of H}_2\text{O} \)

  \[
  \frac{3.5 \text{ mol O}_2}{1 \text{ mol O}_2} \times \frac{2 \text{ mol H}_2\text{O}}{1 \text{ mol O}_2} \times \frac{18 \text{ g H}_2\text{O}}{1 \text{ mol H}_2\text{O}} = 130 \text{ g H}_2\text{O}
  \]
• Mass to Mass. What mass of barium phosphate can be produced from 14.3 g of potassium phosphate reacting with barium nitrate?

\[
2\text{K}_3\text{PO}_4 + 3\text{Ba(NO}_3\text{)}_2 \rightarrow \text{Ba}_3(\text{PO}_4)_2 + 6\text{KNO}_3
\]

pathway: grams of K\text{PO}_4 \rightarrow \text{mol of K}_3\text{PO}_4 \rightarrow \text{mol of Ba}_3(\text{PO}_4)_2 \rightarrow \text{grams of Ba}_3(\text{PO}_4)_2

\[
\begin{array}{c|c|c|c}
\text{14.3 g K}_3\text{PO}_4 & \text{1 mol K}_3\text{PO}_4 & \text{1 mol Ba}_3(\text{PO}_4)_2 & 601.94 \text{ g Ba}_3(\text{PO}_4)_2 \\
\text{212.26 g K}_3\text{PO}_4 & \text{2 mol K}_3\text{PO}_4 & \text{1 mol Ba}_3(\text{PO}_4)_2 & \text{601.94 g Ba}_3(\text{PO}_4)_2 \\
\end{array}
\]

\[= 20.3 \text{ g Ba}_3(\text{PO}_4)_2\]

• What mass of bromine gas can be produced from the complete reaction of potassium bromide and 34.5 g of fluorine gas?

\[
2\text{KBr} + \text{F}_2 \rightarrow \text{Br}_2 + 2\text{KF}
\]

\[
\begin{array}{c|c|c|c}
\text{34.5 g F}_2 & \text{1 mol F}_2 & \text{1 mol Br}_2 & 159.808 \text{ g Br}_2 \\
\text{38 g F}_2 & \text{1 mol F}_2 & \text{1 mol Br}_2 & \text{159.808 g Br}_2 \\
\end{array}
\]

\[= 145 \text{ g Br}_2\]
Mole to Mole Practice

Consider the equation: \( aA \rightarrow bB \)

\[
\frac{\text{Moles of } A}{\text{a moles of } A} \times \frac{\text{b moles of } B}{\text{b moles of } B} = \text{Moles of } B
\]

1) \( N_2 + 3\ H_2 \rightarrow 2\ NH_3 \)

How many moles of hydrogen are needed to completely react with two moles of nitrogen?

\[
\frac{2\ \text{moles } N_2}{1\ \text{moles } N_2} \times \frac{3\ \text{moles } H_2}{1\ \text{moles } N_2} = 6\ \text{moles } H_2
\]

2) \( 2\ KClO_3 \rightarrow 2\ KCl + 3\ O_2 \)

How many moles of oxygen are produced by the decomposition of six moles of potassium chlorate?

\[
\frac{6\ \text{moles } KClO_3}{2\ \text{moles } KClO_3} \times \frac{3\ \text{moles } O_2}{2\ \text{moles } KClO_3} = 9\ \text{moles of } O_2
\]

3) \( Zn + 2\ HCl \rightarrow ZnCl_2 + H_2 \)

How many moles of hydrogen are produced from the reaction of three moles of zinc with an excess of HCl?

\[
\frac{3\ \text{moles } Zn}{1\ \text{moles } Zn} \times \frac{1\ \text{moles } H_2}{1\ \text{moles } Zn} = 3\ \text{moles of } H_2
\]

4) \( C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O \)

How many moles of oxygen are necessary to react completely with four moles of propane (C\(_3\)H\(_8\))?

\[
\frac{4\ \text{moles } C_3H_8}{1\ \text{moles } C_3H_8} \times \frac{5\ \text{moles } O_2}{1\ \text{moles } C_3H_8} = 20\ \text{moles of } O_2
\]

5) \( K_3PO_4 + Al(NO_3)_3 \rightarrow 3\ KNO_3 + AlPO_4 \)

How many moles of potassium nitrate are produced when two moles of potassium phosphate react with two moles of aluminum nitrate?

\[
\frac{2\ \text{moles } K_3PO_4}{1\ \text{moles } K_3PO_4} \times \frac{3\ \text{moles } KNO_3}{1\ \text{moles } K_3PO_4} = 6\ \text{moles of } KNO_3
\]
Consider the following balanced equation to answer 1 – 3.

\[ 2 \text{AgNO}_3(aq) + \text{MgBr}_2(aq) \rightarrow 2 \text{AgBr}(s) + \text{Mg(NO}_3)_2(aq) \]

1) Calculate the mass of silver bromide produced from 0.01 moles of silver nitrate.

\[
\begin{array}{c|c|c|c|c}
0.01 \text{ mol AgNO}_3 & 2 \text{ mol AgBr} & 187.77 \text{ g AgBr} & =2 \text{ g AgBr} \\
2 \text{ mol AgNO}_3 & 1 \text{ mol AgBr} \\
\end{array}
\]

2) Calculate the number of moles of magnesium nitrate formed from 55.3 grams of silver nitrate.

\[
\begin{array}{c|c|c|c|c|c}
55.3 \text{ g AgNO}_3 & 1 \text{ mol AgNO}_3 & 1 \text{ mol Mg(NO}_3)_2 & = 0.163 \text{ mol Mg(NO}_3)_2 \\
169.91 \text{ g AgNO}_3 & 2 \text{ mol AgNO}_3 \\
\end{array}
\]

3) Calculate the number of moles of silver bromide produced from 212 g of magnesium bromide.

\[
\begin{array}{c|c|c|c|c|c}
212 \text{ g MgBr}_2 & 1 \text{ mol MgBr}_2 & 2 \text{ mol AgBr} & = 2.30 \text{ mol AgBr} \\
184.11 \text{ g MgBr}_2 & 1 \text{ mol MgBr}_2 \\
\end{array}
\]

Consider the following balanced equation to answer 4 - 5.

\[ \text{MnO}_2(s) + 4 \text{HCl}(aq) \rightarrow \text{MnCl}_2 + 2 \text{H}_2\text{O}(l) + \text{Cl}_2(g) \]

4) Calculate the mass of MnO\textsubscript{2} required to completely react with 2.5 moles of water.

\[
\begin{array}{c|c|c|c|c}
2.5 \text{ mol H}_2\text{O} & 1 \text{ mol MnO}_2 & 86.94 \text{ g MnO}_2 & = 110 \text{ g MnO}_2 \\
2 \text{ mol H}_2\text{O} & 1 \text{ mol MnO}_2 \\
\end{array}
\]

5) What amount of chlorine gas is produced from 72 grams of HCl?

\[
\begin{array}{c|c|c|c|c|c}
72 \text{ g HCl} & 1 \text{ mol HCl} & 1 \text{ mol Cl}_2 & 70.9 \text{ g Cl}_2 & = 35 \text{ g Cl}_2 \\
36.46 \text{ g HCl} & 4 \text{ mol HCl} & 1 \text{ mol Cl}_2 \\
\end{array}
\]
Mass to Mass Practice

Consider the equation: \( aA \rightarrow bB \)

<table>
<thead>
<tr>
<th>Grams A</th>
<th>1 mol A</th>
<th>b mol B</th>
<th>Molar Mass B</th>
<th>= Mass B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molar Mass A</td>
<td>a mol A</td>
<td>1 mol B</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

How many grams of hydrogen are necessary to completely react with 50.0 g of nitrogen in the above reaction?

\[
\begin{array}{c|c|c|c|c}
50 \text{g N}_2 & 1 \text{mol N}_2 & 3 \text{mol H}_2 & 2.02 \text{g H}_2 & = 10.8 \text{g H}_2 \\
28.02 \text{g N}_2 & 1 \text{mol N}_2 & 1 \text{mol H}_2 & \\
\end{array}
\]

2) \( 2 \text{KClO}_3 \rightarrow 2 \text{KCl} + 3 \text{O}_2 \)

a) How many grams of potassium chloride are produced if 25 grams of potassium chlorate decompose?

\[
\begin{array}{c|c|c|c|c}
25 \text{g KClO}_3 & 1 \text{mol KClO}_3 & 2 \text{mol KCl} & 74.55 \text{g KCl} & = 15 \text{g KCl} \\
122.55 \text{g KClO}_3 & 2 \text{mol KClO}_3 & 1 \text{mol KCl} & \\
\end{array}
\]

b) How many grams of oxygen are produced from 25 grams of potassium chlorate?

\[
\begin{array}{c|c|c|c|c}
25 \text{g KClO}_3 & 1 \text{mol KClO}_3 & 3 \text{mol O}_2 & 32.00 \text{g O}_2 & = 9.8 \text{g O}_2 \\
122.55 \text{g KClO}_3 & 2 \text{mol KClO}_3 & 1 \text{mol O}_2 & \\
\end{array}
\]

3) \( \text{Zn} + 2\text{HCl} \rightarrow \text{ZnCl}_2 + \text{H}_2 \)

How many grams of hydrogen gas are produced from the reaction of 221 grams of zinc with an excess of HCl?

\[
\begin{array}{c|c|c|c|c}
221 \text{g Zn} & 1 \text{mol Zn} & 1 \text{mol H}_2 & 2.02 \text{g H}_2 & = 6.82 \text{g H}_2 \\
65.41 \text{g Zn} & 1 \text{mol Zn} & 1 \text{mol H}_2 & \\
\end{array}
\]

4) Iron will react with oxygen to produce \( \text{Fe}_2\text{O}_3 \). How many grams of \( \text{Fe}_2\text{O}_3 \) will be produced from 37.5 grams of iron. (Hint: write a balanced equation)

\( 4 \text{Fe} + 3 \text{O}_2 \rightarrow 2 \text{Fe}_2\text{O}_3 \)

\[
\begin{array}{c|c|c|c|c}
37.5 \text{g Fe} & 1 \text{mol Fe} & 2 \text{mol Fe}_2\text{O}_3 & 159.7 \text{g Fe}_2\text{O}_3 & = 53.6 \text{g Fe}_2\text{O}_3 \\
55.85 \text{g Fe} & 4 \text{mol Fe} & 1 \text{mol Fe}_2\text{O}_3 & \\
\end{array}
\]
5) $\text{C}_3\text{H}_8 + 5\text{O}_2 \rightarrow 3\text{CO}_2 + 4\text{H}_2\text{O}$

a) How many grams of oxygen are necessary to react completely with 33 grams of propane ($\text{C}_3\text{H}_8$)?

\[
\begin{array}{ccc|c|c}
33 \text{ g C}_3\text{H}_8 & 1 \text{ mol C}_3\text{H}_8 & 5 \text{ mol O}_2 & 32.00 \text{ g O}_2 & = 120 \text{ g O}_2 \\
44.11 \text{ g C}_3\text{H}_8 & 1 \text{ mol C}_3\text{H}_8 & 1 \text{ mol O}_2 & \\
\end{array}
\]

b) How many grams of carbon dioxide are produced in the reaction above?

\[
\begin{array}{ccc|c|c}
33 \text{ g C}_3\text{H}_8 & 1 \text{ mol C}_3\text{H}_8 & 3 \text{ mol CO}_2 & 44.01 \text{ g CO}_2 & = 99 \text{ g CO}_2 \\
44.11 \text{ g C}_3\text{H}_8 & 1 \text{ mol C}_3\text{H}_8 & 1 \text{ mol CO}_2 & \\
\end{array}
\]

c) How many grams of water are produced in the reaction above?

\[
\begin{array}{ccc|c|c}
33 \text{ g C}_3\text{H}_8 & 1 \text{ mol C}_3\text{H}_8 & 4 \text{ mol H}_2\text{O} & 18.02 \text{ g H}_2\text{O} & = 54 \text{ g H}_2\text{O} \\
44.11 \text{ g C}_3\text{H}_8 & 1 \text{ mol C}_3\text{H}_8 & 1 \text{ mol H}_2\text{O} & \\
\end{array}
\]

6) $\text{K}_3\text{PO}_4 + \text{Al(NO}_3)_3 \rightarrow 3 \text{KNO}_3 + \text{AlPO}_4$

How many grams of potassium nitrate are produced from 105 grams of aluminum nitrate?

\[
\begin{array}{ccc|c|c}
105 \text{ g Al(NO}_3)_3 & 1 \text{ mol Al(NO}_3)_3 & 3 \text{ mol KNO}_3 & 101.1 \text{ g KNO}_3 & = 150. \text{ g KNO}_3 \\
213 \text{ g Al(NO}_3)_3 & 1 \text{ mol Al(NO}_3)_3 & 1 \text{ mol KNO}_3 & \\
\end{array}
\]

7) Carbon will react with zinc oxide to produce zinc and carbon dioxide. How many grams of carbon dioxide will be produced if 135 grams of ZnO is completely reacted? (Hint: write a balanced equation)

$\text{C} + 2 \text{ZnO} \rightarrow \text{CO}_2 + 2 \text{Zn}$

\[
\begin{array}{ccc|c|c}
135 \text{ g ZnO} & 1 \text{ mol ZnO} & 1 \text{ mol CO}_2 & 44.01 \text{ g CO}_2 & = 36.5 \text{ g CO}_2 \\
81.41 \text{ g ZnO} & 2 \text{ mol ZnO} & 1 \text{ mol CO}_2 & \\
\end{array}
\]
STOICHIOMETRY PRACTICE

Show ALL work for the following reactions. Be sure to include a complete and balanced reaction.

1) If 95 grams of Iron are needed to react with sulfur, how many grams of sulfur are involved in this reaction? (Iron (III) Product will form)

$$2 \text{Fe} + 3 \text{S} \rightarrow \text{Fe}_2\text{S}_3$$

\[
\begin{array}{c|c|c|c}
\text{Fe} & \text{S} & \text{mol} & \text{mol} \\
95 \text{ g Fe} & 32.07 \text{ g S} & 1 \text{ mol Fe} & 2 \text{ mol S} \\
55.85 \text{ g Fe} & 2 \text{ mol S} & \text{mol} & \text{mol} \\
\end{array}
\]

$$= 82 \text{ g S}$$

2) What mass of Sulfurous acid is produced, when 245g of Sulfur Dioxide is reacted with water?

$$\text{H}_2\text{O} + \text{SO}_2 \rightarrow \text{H}_2\text{SO}_3$$

\[
\begin{array}{c|c|c|c|c}
\text{SO}_2 & \text{H}_2\text{SO}_3 & \text{mol} & \text{mol} \\
245 \text{ g SO}_2 & 82.08 \text{ g H}_2\text{SO}_3 & 1 \text{ mol SO}_2 & 1 \text{ mol H}_2\text{SO}_3 \\
64.07 \text{ g SO}_2 & 1 \text{ mol H}_2\text{SO}_3 & \text{mol} & \text{mol} \\
\end{array}
\]

$$= 314 \text{ g H}_2\text{SO}_3$$

3) If 45g of Sodium Chloride reacts with Silver Nitrate solution, what mass of silver chloride will be produced?

$$\text{NaCl} + \text{Ag(NO}_3\text{)} \rightarrow \text{AgCl} + \text{NaNO}_3$$

\[
\begin{array}{c|c|c|c|c}
\text{NaCl} & \text{AgCl} & \text{mol} & \text{mol} \\
45 \text{ g NaCl} & 143.32 \text{ g AgCl} & 1 \text{ mol NaCl} & 1 \text{ mol AgCl} \\
58.44 \text{ g NaCl} & 1 \text{ mol AgCl} & \text{mol} & \text{mol} \\
\end{array}
\]

$$= 110 \text{ g AgCl}$$

4) When $6.38 \times 10^{18}$ atoms of Chlorine gas reacts with potassium iodide solution, how many grams of potassium chloride are produced?

$$\text{Cl}_2 + 2 \text{KI} \rightarrow 2 \text{KCl} + \text{I}_2$$

\[
\begin{array}{c|c|c|c|c}
\text{Cl}_2 & \text{KCl} & \text{mol} & \text{mol} \\
6.38 \times 10^{18} \text{ atoms Cl}_2 & 74.55 \text{ g KCl} & 1 \text{ mol Cl}_2 & 1 \text{ mol KCl} \\
6.02 \times 10^{23} \text{ atoms Cl}_2 & \text{mol} & \text{mol} & \text{g KCl} \\
\end{array}
\]

$$= 0.00160 \text{ g KCl}$$
5) If 84.9g of solid iron reacts with oxygen gas, (Iron III Product Forms), how many atoms of oxygen will react?

\[
4 \text{Fe} + 3 \text{O}_2 \rightarrow 2 \text{Fe}_2\text{O}_3
\]

\[
\begin{array}{c|c|c|c}
\text{Fe} & \text{O}_2 & \text{mol} & \text{mol} \\
84.9 \text{g} & 55.85 \text{g} & 1 \text{ mol} & 6.02 \times 10^{23} \text{ atoms} \\
55.85 \text{ g} & 4 \text{ mol} & 1 \text{ mol} & \end{array}
\]

\[= 6.86 \times 10^{23} \text{ atoms O}_2\]

6) How many grams of hydrogen gas will be produced from the reaction of zinc metal with 85 grams of Hydrochloric Acid?

\[
\text{Zn} + 2 \text{HCl} \rightarrow \text{ZnCl}_2 + \text{H}_2
\]

\[
\begin{array}{c|c|c|c|c}
\text{HCl} & \text{H}_2 & \text{mol} & \text{mol} & \text{g} \\
85 \text{ g} & 36.46 \text{ g} & 1 \text{ mol} & 2.02 \text{ g} & \\
36.46 \text{ g} & 2 \text{ mol} & 1 \text{ mol} & \end{array}
\]

\[= 2.4 \text{ grams H}_2\]

7) The Haber process for the production of ammonia gas, NH₃, is represented by reacting nitrogen gas with hydrogen gas under special conditions of pressure and temperature. The complete conversion of 90.0 grams of hydrogen to ammonia would require how many atoms of nitrogen gas?

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

\[
\begin{array}{c|c|c|c|c}
\text{N}_2 & \text{H}_2 & \text{mol} & \text{mol} & \text{atm} \\
90.0 \text{ g} & 2.02 \text{ g} & 1 \text{ mol} & 3 \text{ mol} & 6.02 \times 10^{23} \\
2.02 \text{ g} & 3 \text{ mol} & 1 \text{ mol} & \end{array}
\]

\[= 8.94 \times 10^{24} \text{ atom N}_2\]

8) Potassium chlorate decomposes into potassium chloride and oxygen gas. How many grams of oxygen will be produced if 38 grams of potassium chlorate decomposes?

\[
2 \text{KClO}_3 \rightarrow 2 \text{KCl} + 3 \text{O}_2
\]

\[
\begin{array}{c|c|c|c|c|c}
\text{KClO}_3 & \text{KCl} & \text{O}_2 & \text{mol} & \text{mol} & \text{g} \\
2 \text{ mol} & 2 \text{ mol} & 6.02 \times 10^{23} & \text{g} & \\
38 \text{ g} & \text{g} & \end{array}
\]
<table>
<thead>
<tr>
<th>38 g KClO₃</th>
<th>1 mol KClO₃</th>
<th>3 mol O₂</th>
<th>32.00 g O₂</th>
<th>122.55 g KClO₃</th>
<th>2 mol KClO₃</th>
<th>1 mol O₂</th>
</tr>
</thead>
</table>

9) Methane (CH₄) is produced by reacting hydrogen gas with coke (pure carbon). How many grams of methane gas will be produced if \(7.98 \times 10^{24}\) atoms of hydrogen gas are available to react?

\[
\text{C} + 2 \text{H}_2 \rightarrow \text{CH}_4
\]

\[
\downarrow \quad \uparrow
\]

\[
\text{mol} \rightarrow \text{mol}
\]

\[
\text{H}_2 \quad \text{CH}_4
\]

\[
\frac{7.98 \times 10^{24} \text{ atoms H}_2}{6.02 \times 10^{23} \text{ H}_2} \quad 1 \text{ mol H}_2 \quad 1 \text{ mol CH}_4 \quad 16.05 \text{ g CH}_4 = 106 \text{ g CH}_4
\]

10) If 5.0 g of copper metal reacts with a solution of silver nitrate, how many grams of silver metal are recovered? (Copper II Product)

\[
\text{Cu} + 2 \text{AgNO}_3 \rightarrow \text{Cu(NO}_3)_2 + 2 \text{Ag}
\]

\[
\downarrow \quad \uparrow
\]

\[
\text{mol} \rightarrow \text{mol}
\]

\[
\text{Cu} \quad \text{Ag}
\]

\[
\frac{5.0 \text{ g Cu}}{63.55 \text{ g Cu}} \quad 1 \text{ mol Cu} \quad 2 \text{ mol Ag} \quad 107.87 \text{ g Ag} = 17.0 \text{ g Ag}
\]
Molar Volume Notes

- Avogadro’s Law states that ONE MOLE of ANY gas will occupy _________ 
  22.4 L at STP (Standard Temperature and Pressure) ______.
- STP is standard temperature and pressure. The conditions are _________ 
  ____________. STP corresponds to 273 K (0° Celsius) and 1 atm ______.
- What is the volume of 5.68 moles of butane (C₄H₈) at STP?
  
  \[
  \frac{5.68 \text{ mol C}_4\text{H}_8}{1 \text{ mol C}_4\text{H}_8} \times \frac{22.4 \text{ L C}_4\text{H}_8}{1 \text{ mol C}_4\text{H}_8} = 127 \text{ L C}_4\text{H}_8
  \]

- Calculate the number of molecules of 23.5 L of oxygen gas at STP.
  
  \[
  \frac{23.5 \text{ L O}_2}{22.4 \text{ L O}_2} \times \frac{6.02 \times 10^{23} \text{ atoms O}_2}{1 \text{ mol O}_2} = 6.32 \times 10^{23} \text{ atoms O}_2
  \]

- What is the volume of 5.68 g of iodine gas at STP?
  
  \[
  \frac{5.68 \text{ g I}_2}{255.8 \text{ g I}_2} \times \frac{22.4 \text{ L I}_2}{1 \text{ mol I}_2} = 0.499 \text{ L I}_2
  \]
### Volume Practice

1) Find the mass of sugar (C₆H₁₂O₆) required to produce 1.82 L of carbon dioxide gas at STP from the reaction described by the following equation:

\[
C₆H₁₂O₆ + 6O₂ → 6H₂O + 6CO₂
\]

<table>
<thead>
<tr>
<th>1.82 L CO₂</th>
<th>1 mol CO₂</th>
<th>1 mol C₆H₁₂O₆</th>
<th>[ \frac{180.12 \text{ g C₆H₁₂O₆}}{1 \text{ mol C₆H₁₂O₆}} ] = 2.44 g C₆H₁₂O₆</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.4 L CO₂</td>
<td>6 mol CO₂</td>
<td>1 mol C₆H₁₂O₆</td>
<td></td>
</tr>
</tbody>
</table>

2) Find the mass of benzene gas required to produce 2.66 L of carbon dioxide gas at STP using the balanced equation below.

\[
2C₆H₆ + 15O₂ → 6H₂O + 12CO₂
\]

| 2.66 L CO₂ | 1 mol CO₂ | 2 mol C₆H₆ | 78.12 g C₆H₆ | \[ \frac{78.12 \text{ g C₆H₆}}{2 \text{ mol C₆H₆}} \] = 1.55 g C₆H₆ |
|-------------|-------------|-----------------|-----------------|
| 22.4 L CO₂  | 12 mol CO₂ | 1 mol C₆H₆  |

3) Propane gas (C₃H₈) burns in oxygen according to the equation: C₃H₈ + 5O₂ → 3CO₂ + 4H₂O. What volume of carbon dioxide is produced when 2.8 L of oxygen are consumed?

| 2.8 L O₂ | 1 mol O₂ | 3 mol CO₂ | 22.4 L CO₂ | \[ \frac{22.4 \text{ L CO₂}}{1 \text{ mol O₂}} \] = 1.7 L CO₂ |
|-----------|-----------|-------------|-------------|
| 22.4 L O₂ | 5 mol O₂  | 1 mol CO₂   |

4) TNT (trinitrotoluene) decomposes explosively into carbon, carbon monoxide, hydrogen, and nitrogen. What volumes of hydrogen AND nitrogen are produced if 5.8 L of CO is produced? (Hint, you should have an answer for hydrogen AND for nitrogen.)

\[
2C₇H₅(NO₂)₃ → 2C + 12CO + 5H₂ + 3N₂
\]

**vol H₂:**

| 5.8 L CO | 1 mol CO | 5 mol H₂ | 22.4 L H₂ | \[ \frac{22.4 \text{ L H₂}}{1 \text{ mol CO}} \] = 2.4 L H₂ |
|-----------|-----------|-----------|-------------|
| 22.4 L CO | 12 mol CO | 1 mol H₂   |

**vol N₂:**

| 5.8 L CO | 1 mol CO | 3 mol N₂ | 22.4 L N₂ | \[ \frac{22.4 \text{ L N₂}}{1 \text{ mol CO}} \] = 1.5 L N₂ |
|-----------|-----------|-----------|-------------|
| 22.4 L CO | 12 mol CO | 1 mol N₂   |
5) Consider the equation: \(2\text{H}_2\text{S} + 3 \text{O}_2 \rightarrow 2 \text{SO}_2 + 2 \text{H}_2\text{O}\)

a. How many molecules of water are produced when 12 moles of oxygen are reacted?

\[
\begin{array}{ccc}
\text{12 mol } \text{O}_2 & \rightarrow & 2 \text{ mol } \text{H}_2\text{O} \\
3 \text{ mol } \text{O}_2 & \rightarrow & 1 \text{ mol } \text{H}_2\text{O}
\end{array}
\]

\[
\frac{2 \text{ mol } \text{H}_2\text{O}}{1 \text{ mol } \text{H}_2\text{O}} \times 6.02 \times 10^{23} \text{ mlcs H}_2\text{O} = 4.82 \times 10^{24} \text{ mlcs H}_2\text{O}
\]

b. For the reaction, \(8.04 \times 10^{24}\) molecules of \(\text{H}_2\text{S}\) reacts with oxygen. Determine the mass of sulfur dioxide produced.

\[
\begin{array}{ccc}
\text{8.04} \times 10^{24} \text{ mlcs H}_2\text{S} & \rightarrow & 1 \text{ mol } \text{H}_2\text{S} \\
6.02 \times 10^{23} \text{ mlcs H}_2\text{S} & \rightarrow & 2 \text{ mol } \text{H}_2\text{S}
\end{array}
\]

\[
\frac{2 \text{ mol } \text{SO}_2}{2 \text{ mol } \text{H}_2\text{S}} \times 64.07 \text{ g } \text{SO}_2 = 856 \text{ g } \text{SO}_2
\]

6) Consider the reaction: \(\text{Sb}_2\text{O}_3 + 3 \text{ C} \rightarrow 2 \text{ Sb} + 3 \text{ CO}\)

a. How many molecules of carbon monoxide are produced when 1.423 grams of \(\text{Sb}_2\text{O}_3\) are reacted?

\[
\begin{array}{ccc}
\text{1.423 g } \text{Sb}_2\text{O}_3 & \rightarrow & 1 \text{ mol } \text{Sb}_2\text{O}_3 \\
291.5 \text{ g } \text{Sb}_2\text{O}_3 & \rightarrow & 1 \text{ mol } \text{Sb}_2\text{O}_3
\end{array}
\]

\[
\begin{array}{ccc}
3 \text{ mol } \text{CO} & \rightarrow & 6.02 \times 10^{23} \text{ mlcs CO} \\
1 \text{ mol } \text{CO} & \rightarrow & 1 \text{ mol } \text{CO}
\end{array}
\]

\[
\frac{3 \text{ mol } \text{CO}}{1 \text{ mol } \text{CO}} \times 6.02 \times 10^{23} \text{ mlcs CO} = 8.81 \times 10^{21} \text{ mlcs CO}
\]

b. For the reaction, \(3.01 \times 10^{22}\) molecules of carbon are reacted. Determine the mass of antimony (Sb) produced.

\[
\begin{array}{ccc}
3.01 \times 10^{22} \text{ mlcs C} & \rightarrow & 1 \text{ mol } \text{C} \\
6.02 \times 10^{23} \text{ mlcs C} & \rightarrow & 3 \text{ mol } \text{C}
\end{array}
\]

\[
\frac{2 \text{ mol } \text{Sb}}{3 \text{ mol } \text{C}} \times 121.75 \text{ g } \text{Sb} = 4.06 \text{ g } \text{Sb}
\]

c. If the reaction of 12.01 grams of carbon occurs at STP, how many liters of carbon monoxide gas are produced?

\[
\begin{array}{ccc}
12.01 \text{ g } \text{C} & \rightarrow & 1 \text{ mol } \text{C} \\
3 \text{ mol } \text{C} & \rightarrow & 22.4 \text{ L } \text{CO}
\end{array}
\]

\[
\frac{3 \text{ mol } \text{CO}}{1 \text{ mol } \text{CO}} \times 22.4 \text{ L } \text{CO} = 22.4 \text{ L } \text{CO}
\]
Mixed Practice

1. In a very violent reaction called a thermite reaction, aluminum metal reacts with iron(III) oxide to form iron metal and aluminum oxide according to the following equation: \( \text{Fe}_2\text{O}_3 + 2\text{Al} \rightarrow 2\text{Fe} + \text{Al}_2\text{O}_3 \)
   a. What mass of Al will react with 150 g of \( \text{Fe}_2\text{O}_3 \)?

   \[ 51 \]

   b. If 0.905 mol \( \text{Al}_2\text{O}_3 \) is produced in the reaction, what mass of Fe is produced?

   \[ 101 \]

   c. How many moles of \( \text{Fe}_2\text{O}_3 \) will react with 99.0 g of Al?

   \[ 1.83 \]

2. Ammonium nitrate decomposes to yield nitrogen gas, water, and oxygen gas in the following reaction: \( 2\text{NH}_4\text{NO}_3 \rightarrow 2\text{N}_2 + \text{O}_2 + 4\text{H}_2\text{O} \)
   a. How many moles of nitrogen gas are produced when 36.0 g of \( \text{NH}_4\text{NO}_3 \) reacts?

   \[ 0.450 \]

   b. If 7.35 mol of \( \text{H}_2\text{O} \) are produced in this reaction, what mass of \( \text{NH}_4\text{NO}_3 \) reacted?

   \[ 294 \]

3. Lead(II) nitrate reacts with potassium iodide to produce lead(II) iodide and potassium nitrate. If 1.23 mg of lead nitrate are consumed, what is the mass of the potassium nitrate produced? (Hint: write a balanced equation for the reaction.)

   \[ 7.51 \times 10^{-4} \]
4. In a space shuttle, the CO$_2$ that the crew exhales is removed from the air by a reaction within canisters of lithium hydroxide. On average, each astronaut exhales about 20.0 mol of CO$_2$ daily. The other product of the reaction is Li$_2$CO$_3$.
   a. Write a balanced equation for this reaction.
   \[ \text{CO}_2 + 2 \text{LiOH} \rightarrow \text{Li}_2\text{CO}_3 + \text{H}_2\text{O} \]
   b. What mass of water will be produced when this amount reacts with LiOH?
   \[ 360 \] 
   c. How many molecules of water will be produced if the five member crew exhales 4400 grams of CO$_2$?
   \[ 6 \times 10^{25} \]

5. A reaction between hydrazine, N$_2$H$_4$, and dinitrogen tetroxide, N$_2$O$_4$, has been used to launch rockets into space. The reaction produces nitrogen gas and water vapor.
   a. Write a balanced chemical equation for this reaction.
   \[ 2 \text{N}_2\text{H}_4 + \text{N}_2\text{O}_4 \rightarrow 3 \text{N}_2 + 4 \text{H}_2\text{O} \]
   b. How many moles of N$_2$ will be produced if 20,000 mol of N$_2$O$_4$ are used by a rocket?
   \[ 60,000 \]
   c. How many grams of H$_2$O are made when 450 L of N$_2$O$_4$ are consumed at STP?
   \[ 1400 \text{ or } 1.4 \times 10^3 \]
Limiting Reactants Notes

- In all reactions, there will be one reactant that will “limit” the yield of the product. **The limiting reactant is not always the one present in the smallest quantity- the MOLAR RATIO needs to be taken into consideration.**

- What mass of aluminum sulfide can be produced from 9.00 g of aluminum reacting with 8.00 g of sulfur? What is your limiting reactant?

  \[ 2 \text{Al} + 3 \text{S} \rightarrow \text{Al}_2\text{S}_3 \]

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Mole</th>
<th>Mole Al₂S₃</th>
<th>Mass Al₂S₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.00 g Al</td>
<td>1 mol Al</td>
<td>2 mol Al₂S₃</td>
<td>150.17 g Al₂S₃</td>
</tr>
<tr>
<td>26.98 g Al</td>
<td>1 mol Al₂S₃</td>
<td>1 mol Al₂S₃</td>
<td>= 25.1 g Al₂S₃</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Mole</th>
<th>Mole Al₂S₃</th>
<th>Mass Al₂S₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.00 g S</td>
<td>1 mol S</td>
<td>1 mol Al₂S₃</td>
<td>150.17 g Al₂S₃</td>
</tr>
<tr>
<td>32.07 g S</td>
<td>3 mol S</td>
<td>1 mol Al₂S₃</td>
<td>= 12.5 g Al₂S₃</td>
</tr>
</tbody>
</table>

There will be 12.5 g of Al₂S₃ produced and Sulfur is the limiting reactant.

- What mass of aluminum sulfate can be produced from the reaction of 20.0 g of sulfuric acid with 25.0 g of aluminum hydroxide?

  \[ 3 \text{H}_2\text{SO}_4 + 2 \text{Al(OH)}_3 \rightarrow \text{Al}_2(\text{SO}_4)_3 + 6 \text{H}_2\text{O} \]

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Mole</th>
<th>Mole Al₂(SO₄)₃</th>
<th>Mass Al₂(SO₄)₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.0 g H₂SO₄</td>
<td>1 mol H₂SO₄</td>
<td>1 mol Al₂(SO₄)₃</td>
<td>342.17 g Al₂(SO₄)₃</td>
</tr>
<tr>
<td>98.09 g H₂SO₄</td>
<td>3 mol H₂SO₄</td>
<td>1 mol Al₂(SO₄)₃</td>
<td>= 23.3 g Al₂(SO₄)₃</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Mole</th>
<th>Mole Al₂(SO₄)₃</th>
<th>Mass Al₂(SO₄)₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.0 g Al(OH)₃</td>
<td>1 mol Al(OH)₃</td>
<td>1 mol Al₂(SO₄)₃</td>
<td>342.17 g Al₂(SO₄)₃</td>
</tr>
<tr>
<td>78.01 g Al(OH)₃</td>
<td>2 mol Al(OH)₃</td>
<td>1 mol Al₂(SO₄)₃</td>
<td>= 54.8 g Al₂(SO₄)₃</td>
</tr>
</tbody>
</table>

  - What mass of the excess reactant will remain at the completion of the reaction?

    There will be 23.3 g Al₂(SO₄)₃ produced and Sulfuric acid (H₂SO₄) is the limiting reactant.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Mole</th>
<th>Mole Al₂(SO₄)₃</th>
<th>Mass Al₂(SO₄)₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.3 g Al₂(SO₄)₃</td>
<td>1 mol Al₂(SO₄)₃</td>
<td>2 mol Al(OH)₃</td>
<td>78.01 g Al(OH)₃</td>
</tr>
<tr>
<td>342.17 g Al₂(SO₄)₃</td>
<td>1 mol Al₂(SO₄)₃</td>
<td>1 mol Al(OH)₃</td>
<td>= 10.6 g Al(OH)₃</td>
</tr>
</tbody>
</table>

We started with 25.0 g Al(OH)₃ and used 10.6 g. We are left with 14.4 g of Al(OH)₃.
What mass of zinc sulfide can be produced from the reaction of 130.8 g of zinc reacting with 256.6 g of sulfur? Indicate the limiting reactant.

\[
\text{Zn} + \text{S} \rightarrow \text{ZnS}
\]

- There will be 195.0 g ZnS produced and Zinc (Zn) is the limiting reactant.

- What mass of the excess reactant will remain at the completion of the reaction?

  - There would be 195.0 g ZnS produced when 130.8 g of Zinc (Zn) reacts and Zinc (Zn) is the limiting reactant. Therefore work backwards using 195.0 grams of ZnS. Once you find the amount produced subtract it form the amount of Sulfur you are given.

\[
\text{Zn} + \text{S} \rightarrow \text{ZnS}
\]

Initial amount of excess reactant - amount used (based on limiting reactant) = amount left

\[
256.6 \text{ g of S} - 64.17 \text{ g of S} = 192.43 \text{ g of S}
\]

**Short cut:**

\[
\text{Initial amount of excess reactant} - \left(\frac{\text{Initial amount of excess reactant}}{\text{amount formed by limiting reactant}} \times \text{amount formed by excess reactant}\right) = \text{amount of excess reactant left}
\]

\[
256.6 \text{ g S} - \left(\frac{256.6 \text{ g S} \times 195.0 \text{ g}}{779.7 \text{ g}}\right) = 192.43 \text{ grams of S will be left over}
\]
Limiting Reactants

1. Sodium chloride can be prepared by reacting sodium metal with chlorine gas. Write and balance the chemical equation for this process.

\[ 2 \text{Na} + \text{Cl}_2 \rightarrow 2 \text{NaCl} \]

a. How many grams of sodium chloride will be produced when 6.70g of sodium reacts with 3.20g of chlorine gas?

5.27 g NaCl

b. Which is the limiting reactant? Cl₂

2. Hydrogen gas can be formed in the laboratory by the reaction of magnesium metal with hydrochloric acid (HCl). Write and balance the reaction for this process.

\[ \text{Mg} + 2 \text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2 \]

a. How many grams of hydrogen can be produced when 6.00 g of HCl is added to 5.00 g of Mg?

0.165 g H₂

b. Which of the reactants is the limiting reagent? HCl

3. Hydrazine, or dinitrogen tetrahydride, is used as rocket fuel. It reacts with oxygen to form nitrogen gas and water. Write and balance the equation for this process.

\[ \text{N}_2\text{H}_4 + \text{O}_2 \rightarrow \text{N}_2 + 2 \text{H}_2\text{O} \]

a. How many liters will be formed from 1.0 g of hydrazine reacts with 1.0 g of oxygen?

0.70 L N₂

b. Indicate the limiting reactant Neither!

4. Silicon dioxide can be converted to silicon monocarbide by a reaction with carbon. Write and balance the equation for this process.

\[ \text{SiO}_2 + \text{C} \rightarrow \text{SiC} + \text{O}_2 \]

a. What mass of silicon monocarbide can be formed from reacting 67.3 grams of silicon dioxide with 24.5 g of carbon?

44.9 g SiC

b. Identify the limiting reactant.

\[ \text{SiO}_2 \]
5. Pure antimony can be obtained by reacting a sulfide ore of antimony (antimony (III) sulfide) with Iron. (Iron (II) product) Write and balance the equation for this process.

\[
\text{Sb}_2\text{S}_3 + 3 \text{Fe} \rightarrow 3 \text{FeS} + 2 \text{Sb}
\]

a. What mass of antimony can be obtained from reacting 56.8 g of the ore with 60.5 g of Iron?

40.7 g Sb

b. Identify the limiting reactant.

\text{Sb}_2\text{S}_3
Percent Yield Notes

- Percent yield shows how effective the reaction is!

- Adipic acid, $\text{H}_2\text{C}_6\text{H}_8\text{O}_4$, is a material used for the production of nylon. It is made commercially by a controlled reaction between cyclohexane ($\text{C}_6\text{H}_{12}$) and oxygen gas. Water is a byproduct of the reaction. The controlled combustion of 25.0 g of cyclohexane will produce 33.5 g of adipic acid. Calculate the percent yield.

- Bornite ($\text{CuFeS}_3$) is a copper ore used in the production of copper. When heated with oxygen gas, pure copper is obtained along with Iron (II) oxide and sulfur dioxide. If $2.50 \times 10^3$ kg of bornite is heated with excess oxygen and the reaction proceeds at an 86.3% yield, how much copper is produced?

- If 15.0 g of nitrogen reacts with 15.0 g of hydrogen, 10.5 g of ammonia is produced experimentally. What is the percent yield of this reaction?
% YIELD OF REACTIONS

1. Calcium carbonate decomposes into calcium oxide and carbon dioxide. Calculate the % yield if 97.5 g of carbon dioxide is recovered from 235.0 g of calcium carbonate.

\[
\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2
\]

\[
\begin{array}{c|c|c|c}
\text{235.0 g} & \text{1 mol CaCO}_3 & \text{1 mol CO}_2 & \text{44.01 g CO}_2 \\
\hline
\text{100.9 g} & \text{1 mol CaCO}_3 & \text{1 mol CO}_2 & \text{102.5 g CO}_2 \\
\end{array}
\]

\[
\text{Experimental yield} \times 100 = \% \text{ yield} \quad 97.5 \text{ g} \times 100 = 95.12\%
\]

\[
\text{Theoretical yield} \quad 102.5 \text{ g}
\]

2. Zirconium (IV) iodide is decomposed to obtain pure zirconium. What is the % yield for this process if 5.00g of pure zirconium is obtained from the decomposition of 45.0 g of Zirconium (IV) iodide?

\[
\text{ZrI}_4 \rightarrow \text{Zr} + 2 \text{ I}_2
\]

\[
\begin{array}{c|c|c|c}
\text{45.00 g} & \text{1 mol ZrI}_4 & \text{1 mol Zr} & \text{91.22 g Zr} \\
\hline
\text{601.6 g} & \text{1 mol ZrI}_4 & \text{1 mol Zr} & \text{6.85 g Zr} \\
\end{array}
\]

\[
\text{Experimental yield} \times 100 = \% \text{ yield} \quad 5.00 \text{ g} \times 100 = 73\%
\]

\[
\text{Theoretical yield} \quad 6.85 \text{ g}
\]

73 %

3. If 15.0 g of nitrogen reacts with 15.0 g of hydrogen, 10.5 g of ammonia is produced. Calculate the % yield of this reaction.

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

57 %

4. Silicon dioxide and hydrofluoric acid (hydrogen fluoride) react to produce hexafluorosilicic acid (H$_2$SiF$_6$) and water. Calculate the % yield if 40.0 g of silicon dioxide reacts with 40.0 g of hydrofluoric acid and 45.8g of hexafluorosilicic acid is produced.

\[
\text{SiO}_2 + 6 \text{HF} \rightarrow \text{H}_2\text{SiF}_6 + 2 \text{H}_2\text{O}
\]

95.4 %
5. What mass of aluminum oxide will form if the reaction of 34.5 g of aluminum and 45.0 L of oxygen gas proceeds at a 78.2% yield?

\[4 \text{ Al} + 3 \text{ O}_2 \rightarrow 2 \text{ Al}_2\text{O}_3\]

51.0 g Al₂O₃
Limiting Reactants & Percent Yield

1. Identify the limiting and excess reagents when 25 L of nitrogen reacts with 25 L of hydrogen at STP. How many liters of ammonia gas are formed in this reaction?

\[ \text{_____ N}_2 + \text{3 H}_2 \rightarrow \text{2 NH}_3 \]

17

2. If 6.57 g of iron are reacted with an excess of hydrochloric acid, HCl, then hydrogen gas and 14.63 g of iron(III) chloride are obtained. Calculate the theoretical yield and percent yield of FeCl₃.

\[ \text{2 Fe} + \text{6 HCl} \rightarrow \text{3 H}_2 + \text{2 FeCl}_3 \]

19.1, 76.6

3. A chemist burns 160. g of aluminum in oxygen to produce aluminum oxide. She produces 260. g of aluminum oxide. Write a balanced equation and calculate the theoretical yield and percent yield.

302, 86.1

4. You need to produce 100.0 g of FeCl₃ in the reaction from #2. If the percent yield of the reaction is 85%, how many grams of iron do you need to start with?

40.49
Unit 8 Test Review

1. What is the volume of 67.4 g of hydrogen gas at STP?

\[
\begin{array}{ccc}
67.4 \text{ g } \text{H}_2 & 1 \text{ mol } \text{H}_2 & 22.4 \text{ L } \text{H}_2 \\
2.02 \text{ g } \text{H}_2 & 1 \text{ mol } \text{H}_2 & \\
\end{array}
\]

\[= \frac{747 \text{ L } \text{H}_2}{1 \text{ mol } \text{H}_2}\]

\[747 \text{ L } \text{H}_2\]

2. What is the volume of 56.8 g of chlorine gas at STP.

\[
\begin{array}{ccc}
56.8 \text{ g } \text{Cl}_2 & 1 \text{ mol } \text{Cl}_2 & 22.4 \text{ L } \text{Cl}_2 \\
70.90 \text{ g } \text{Cl}_2 & 1 \text{ mol } \text{Cl}_2 & \\
\end{array}
\]

\[= \frac{17.945 \text{ L } \text{Cl}_2}{1 \text{ mol } \text{Cl}_2}\]

\[17.9 \text{ L } \text{Cl}_2\]

3. If 95 grams of Iron are needed to react with sulfur, how many grams of sulfur are involved in this reaction? (Iron (III) Product will form)

\[2 \text{ Fe } + 3 \text{ S } \rightarrow \text{ Fe}_2\text{S}_3\]

\[
\begin{array}{ccc}
95 \text{ g } \text{Fe} & 1 \text{ mol } \text{Fe} & 3 \text{ mol } \text{S} \\
55.85 \text{ g } \text{Fe} & 2 \text{ mol } \text{Fe} & 1 \text{ mol } \text{S} \\
\end{array}
\]

\[= \frac{81.647 \text{ g } \text{S}}{1 \text{ mol } \text{S}}\]

\[82 \text{ g } \text{S}\]

4. What mass of Sulfurous acid is produced, when 245g of Sulfur Dioxide is reacted with water?

\[\text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_3\]

\[
\begin{array}{ccc}
245 \text{ g } \text{SO}_2 & 1 \text{ mol } \text{SO}_2 & 82.09 \text{ g } \text{H}_2\text{SO}_3 \\
64.07 \text{ g } \text{SO}_2 & 1 \text{ mol } \text{H}_2\text{SO}_3 & \\
\end{array}
\]

\[= \frac{313.907 \text{ g } \text{H}_2\text{SO}_3}{1 \text{ mol } \text{H}_2\text{SO}_3}\]

\[314 \text{ g } \text{H}_2\text{SO}_3\]

5. If 45g of Sodium Chloride reacts with Silver Nitrate solution, what mass of silver chloride will be produced?

\[\text{AgNO}_3 + \text{NaCl} \rightarrow \text{AgCl} + \text{NaNO}_3\]

\[
\begin{array}{ccc}
45 \text{ g } \text{NaCl} & 1 \text{ mol } \text{NaCl} & 143.32 \text{ g } \text{AgCl} \\
58.44 \text{ g } \text{NaCl} & 1 \text{ mol } \text{NaCl} & \\
\end{array}
\]

\[= \frac{110.36 \text{ g } \text{AgCl}}{1 \text{ mol } \text{AgCl}}\]

\[110 \text{ g } \text{AgCl}\]
6. When 78.2 L of Chlorine gas reacts with potassium iodide solution, how many grams of potassium chloride are produced?

\[
\text{Cl}_2 + 2 \text{KI} \rightarrow 2 \text{KCl} + \text{I}_2
\]

<table>
<thead>
<tr>
<th>78.2 L Cl₂</th>
<th>1 mol Cl₂</th>
<th>2 mol KCl</th>
<th>74.55 g KCl</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.4 L Cl₂</td>
<td>1 mol Cl₂</td>
<td>1 mol KCl</td>
<td></td>
</tr>
</tbody>
</table>

= 519.188 g KCl

519 g KCl

7. If 84.9g of solid iron reacts with oxygen gas. (Iron III product forms), what volume of oxygen will react?

\[
4 \text{Fe} + 3 \text{O}_2 \rightarrow 2 \text{Fe}_2\text{O}_3
\]

<table>
<thead>
<tr>
<th>84.9 g Fe</th>
<th>1 mol Fe</th>
<th>3 mol O₂</th>
<th>22.4 L O₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>55.85 g Fe</td>
<td>4 mol Fe</td>
<td>1 mol O₂</td>
<td></td>
</tr>
</tbody>
</table>

= 25.538 L O₂

25.5 L O₂

8. How many grams of hydrogen gas will be produced from the reaction of zinc metal with 85 grams of Hydrochloric Acid?

\[
\text{Zn} + 2 \text{HCl} \rightarrow \text{ZnCl}_2 + \text{H}_2
\]

<table>
<thead>
<tr>
<th>85 g HCl</th>
<th>1 mol HCl</th>
<th>1 mol H₂</th>
<th>2.02 g H₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>36.46 g HCl</td>
<td>2 mol HCl</td>
<td>1 mol H₂</td>
<td></td>
</tr>
</tbody>
</table>

= 2.3546 g H₂

2.4 g H₂

9. The Haber process for the production of ammonia gas, NH₃ is represented by reacting nitrogen gas with hydrogen gas under special conditions of pressure and temperature. The complete conversion of 90.0 grams of hydrogen to ammonia would require how many liters of nitrogen gas?

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

<table>
<thead>
<tr>
<th>90 g H₂</th>
<th>1 mol H₂</th>
<th>1 mol N₂</th>
<th>22.4 L N₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.02 g H₂</td>
<td>3 mol H₂</td>
<td>1 mol N₂</td>
<td></td>
</tr>
</tbody>
</table>

= 332.673 L N₂

333 L N₂
10. Potassium chlorate decomposes into potassium chloride and oxygen gas. How many grams of oxygen will be produced if 38 grams of potassium chlorate decomposes?

\[ 2 \text{ KClO}_3 \rightarrow 2 \text{ KCl} + 3 \text{ O}_2 \]

<table>
<thead>
<tr>
<th>38 g KClO\textsubscript{3}</th>
<th>1 mol KClO\textsubscript{3}</th>
<th>3 mol O\textsubscript{2}</th>
<th>32.00 g O\textsubscript{2}</th>
<th>= 14.8837 g O\textsubscript{2}</th>
</tr>
</thead>
<tbody>
<tr>
<td>122.55 g KClO\textsubscript{3}</td>
<td>2 mol KClO\textsubscript{3}</td>
<td>1 mol O\textsubscript{2}</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

15 g O\textsubscript{2}

11. Identify the limiting reactant when 10.7 g of Silver reacts with 8.9 L of chlorine gas at STP? What mass of product can be formed?

\[ 2 \text{ Ag} + \text{ Cl}_2 \rightarrow 2 \text{ AgCl} \]

<table>
<thead>
<tr>
<th>10.7 g Ag</th>
<th>1 mol Ag</th>
<th>2 mol AgCl</th>
<th>143.32 g AgCl</th>
<th>= 14.22 g AgCl</th>
</tr>
</thead>
<tbody>
<tr>
<td>107.87 g Ag</td>
<td>2 mol Ag</td>
<td>1 mol AgCl</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>8.9 g Cl\textsubscript{2}</th>
<th>1 mol Cl\textsubscript{2}</th>
<th>2 mol AgCl</th>
<th>143.32 g AgCl</th>
<th>= 113.89 g AgCl</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.4 L Cl\textsubscript{2}</td>
<td>1 mol Cl\textsubscript{2}</td>
<td>1 mol AgCl</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Ag is the limiting reactant) 14.2 g AgCl

12. Identify the limiting reactant when 18.2 g of H\textsubscript{2}O reacts with 14 g K. What mass of KOH is formed?

\[ 2 \text{ K} + 2 \text{ H}_2\text{O} \rightarrow \text{ H}_2 + 2 \text{ KOH} \]

<table>
<thead>
<tr>
<th>14 g K</th>
<th>1 mol K</th>
<th>2 mol KOH</th>
<th>56.11 g KOH</th>
<th>= 20.09 g KOH</th>
</tr>
</thead>
<tbody>
<tr>
<td>39.10 g K</td>
<td>2 mol K</td>
<td>1 mol KOH</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>18.2 g H\textsubscript{2}O</th>
<th>1 mol H\textsubscript{2}O</th>
<th>2 mol KOH</th>
<th>56.11 g KOH</th>
<th>= 56.67 g KOH</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.02 g H\textsubscript{2}O</td>
<td>2 mol H\textsubscript{2}O</td>
<td>1 mol KOH</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

20. g KOH
13. Identify the limiting reactant when 85.2 g of H$_2$S at STP is reacted with 18.0 g of NaOH. What mass of H$_2$O is produced?

$$2 \text{ NaOH} + \text{ H}_2\text{S} \rightarrow 2 \text{ H}_2\text{O} + \text{ Na}_2\text{S}$$

<table>
<thead>
<tr>
<th></th>
<th>85.2 g H$_2$S</th>
<th>1 mol H$_2$S</th>
<th>2 mol H$_2$O</th>
<th>18.02 g H$_2$O</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>34.09 g H$_2$S</td>
<td>1 mol H$_2$S</td>
<td>1 mol H$_2$O</td>
<td></td>
</tr>
</tbody>
</table>

$$18.2 \text{ g NaOH} | 1 \text{ mol NaOH} | 2 \text{ mol H}_2\text{O} | 18.02 \text{ g H}_2\text{O} = 8.199 \text{ g H}_2\text{O}$$

8.20 g H$_2$O

14. When 45.0L of chlorine gas reacts with excess aluminum, 165g of aluminum chloride are produced. What is your % yield?

$$2 \text{ Al} + 3 \text{ Cl}_2 \rightarrow 2 \text{ AlCl}_3$$

<table>
<thead>
<tr>
<th></th>
<th>45.0 g Cl$_2$</th>
<th>1 mol Cl$_2$</th>
<th>2 mol AlCl$_3$</th>
<th>133.33 g AlCl$_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>22.4 L Cl$_2$</td>
<td>3 mol Cl$_2$</td>
<td>1 mol AlCl$_3$</td>
<td></td>
</tr>
</tbody>
</table>

Theoretical = 178 g AlCl$_3$

Experimental yield $\times$ 100 = % yield

$$\frac{165 \text{ g}}{178 \text{ g}} \times 100 = 92.7\%$$
Adipic Acid, $H_2C_6H_8O_4$, is used to produce nylon. It is made commercially by a controlled reaction between cyclohexane ($C_6H_{12}$) and $O_2$ as presented in the following UNBALANCED reaction.

$$2 \text{C}_6\text{H}_{12} + 5 \text{O}_2 \rightarrow 2 \text{H}_2\text{C}_6\text{H}_8\text{O}_4 + 2 \text{H}_2\text{O}$$

Assume that you carry out this reaction starting with 25.0 g of cyclohexane and excess oxygen. The reaction proceeds at a 77.0% yield. How many grams of adipic acid can you produce?

Theoretical $= 43.4$ g $H_2C_6H_8O_4$

Experimental yield $\times 100 = \%$ yield

$$\text{EXP} \times 100 = 77.0\%$$

$$\text{EXP} = (0.770) (43.4)$$

$$\text{EXP} = 33.4 \text{ g } H_2C_6H_8O_4$$

Iron ore containing iron (III) oxide is converted into iron by way of reacting it with carbon monoxide to produce iron and carbon dioxide. If you start with 150. g of iron ore in the presence of excess CO and the reaction proceeds at an 83.7% yield, what mass of iron can be obtained?

$$\text{Fe}_2\text{O}_3 + 3 \text{CO} \rightarrow 3 \text{CO}_2 + 2 \text{Fe}$$

Theoretical $= 105$ g Fe

Experimental yield $\times 100 = \%$ yield

$$\text{EXP} \times 100 = 83.7\%$$

$$\text{EXP} = (0.837) (105)$$

$$\text{EXP} = 87.9 \text{ g Fe}$$