CHAPTER 12
STOICHIOMETRY

12.1 Using Everyday Equations

- Stoichiometry is the calculation of quantities using different substances in chemical equations.
- Based on the Law of Conservation of Mass.

* The balanced equation gives the ratios for the reactants and products.
* 1 mole of Mg reacts with 2 moles of HCl
* 1 mole of $MgCl_2$ and 1 mole of H_2 are produced

$$Mg(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2(g)$$

- How many moles of HCl are needed to react 2 moles of Mg?
- How many moles of H_2 are produced if 6 moles of HCl reacts?
- How much Magnesium is needed to produce 7.6 moles of $MgCl_2$?

Chemists use balanced chemical equations as a basis to calculate how much reactant is needed or product is formed in a reaction.

Ratios in chemical equations

$$4Fe(s) + 3O_2(g) \longrightarrow 2Fe_2O_3(s)$$

What are the possible mole ratios?

$$N_2 + 3H_2 \longrightarrow 2NH_3$$

What is conserved in a Chemical Reaction?		
Atoms		Atoms
Mass		Mass
Moles		Moles
Molecules		Molecules
Volume		Volume

What is Conserved in Chemical Equations?

- Mass & atoms always!
- Volume is not because temp. or pressure can change.
- Moles, molecules, and formula units are not because atoms rearrange in a chemical reaction.

In a balanced chemical equation, mass & atoms are conserved...

$$4Fe(s) + 3O_2(g) \longrightarrow 2Fe_2O_3(s)$$

4 mol Fe	55.85 g / 1 mol Fe	223.4 - g Fe	Total Mass of Reactant 319.4 - grams
3 mol O_2	32.00 g / 1 mol O_2	96.00 - g O_2	
2 mol Fe_2O_3	159.7 g / 1 mol Fe_2O_3	319.4 - g Fe_2O_3	Total Mass of Product 319.4 - grams

Mole Ratios in chemical equations

- Ratio between the number of moles of any two substances in a balanced equation. $N_2 + 3H_2 \rightarrow 2NH_3$
- Can change but should be listed in lowest whole number form.
- Lowest Whole-number Ratios are used during mole to mole conversions.

Excess vs. Limiting

- What does excess mean?
- If you have excess reagent, that means you have plenty of it.

Reagent = Reactant

3 eggs + 2 cups Flour + 1 Cup sugar ⟶ 1 cake

You have:

> 12 eggs
> 10 cups Flour
> 8 cups sugar

Which ingredient limits the number of cakes you can bake?

Which ingredients do you have an excess of?

12.2 Stoichiometric Calculations

- Mole-Mole Calculations
- Begin with a mole quantity
- End with a mole quantity
- One step operation

Stoichiometric Pathways

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

How would you convert volume of nitrogen gas into mass of nitrogen trihydride @ STP?

$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$

How would you convert atoms of zinc into volume of hydrogen gas @ STP?

How would you convert moles of Zinc into formula units of zinc chloride?

More Mole-Mole Calculations

Aluminum metal reacts with hydrochloric in a single replacement reaction. How many moles of hydrochloric acid are required to react with 7.5 moles of Aluminum?

More Mole-Mole Calculations

Aluminum metal reacts with oxygen in a synthesis reaction. How many moles of product can be made from 7.8×10^{-1} moles of oxygen gas?

More Mole-Mole Calculations

$4Al + 3O_2 \rightarrow 2Al_2O_3$

How many moles of Al is needed to make 3.7 mol of Al_2O_3?

Mass-Mass Calculations

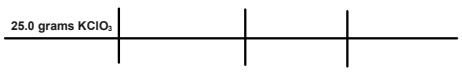
- 3 step process
- Molar Masses required

1. Change mass to moles
2. Mole - mole ratio
3. Change mole to mass

Mass-Mass Calculations

$2KClO_3 \rightarrow 2KCl + 3O_2$

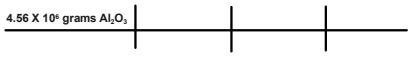
What mass of KCl is produced from 25.0-g of $KClO_3$?



Mass-Mass Calculations

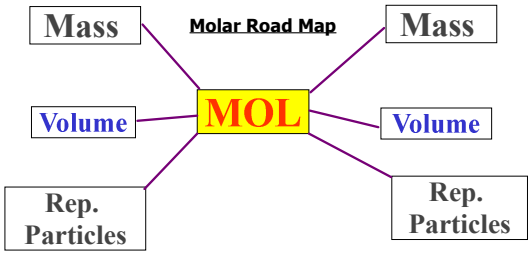
$4Al + 3O_2 \rightarrow 2Al_2O_3$

How many grams of Al is needed to form 4.56×10^6 grams of Al_2O_3 with an excess of oxygen?



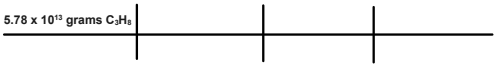
Other Stoichiometric Calculations

- Stoichiometry calculations may include any unit of measurement that is related to the mole.
- Molar Road Map



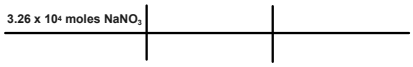
Stoichiometric Calculations

5.78×10^{13} grams of tricarbon octahydride is in a combustion reaction. How many molecules of water are produced in this reaction?



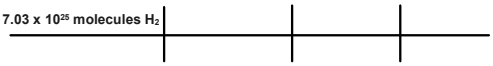
Stoichiometric Calculations

Aqueous sodium nitrate reacts with aqueous copper (II) phosphate in a double replacement reaction. How many formula units of copper (II) nitrate are produced from 3.26×10^4 moles of sodium nitrate?



Stoichiometric Calculations

Assuming STP, how many liters of ammonia are produced from 7.03×10^{25} molecules of hydrogen gas reacting with an excess of nitrogen?



12.3 Limiting Reactants

- Reactant that is used up first in a chemical reaction, or what you will run out of first.
- It determines the amount of product that can be formed.
- This must be determined when you are given the amounts of two or more reactants.

Limiting & Excess Reactants

- If you have more than 1 reactant, the likelihood of having the exact same ratio required is very small.
- You are very likely to run out of one reactant before the other, hence, stopping the reaction.
- The reaction stops when the limiting reactant runs out, therefore, having excess of the other reactant.

Example for Understanding

You are making omelet's...

- **Each omelet needs 3 eggs and 1 cup of cheese.**
- **You have 12 eggs and 10 cups of cheese.**

3 eggs + 1 cups cheese → 1 omelet

- How many omelets can you make?
- Which ingredient limits the number of omelets you can make?
- Which ingredient will you have an excess of?

Determining Limiting Reagent

- Using the amounts of substances present, perform a mol-mol conversion for each. This gives you the amount needed.
- Compare the amount needed with the amount present.
- Whichever substance has too little present is the limiting reagent.

* when given both reactants

Example #1: $2Na + Cl_2 \rightarrow 2NaCl$

Given 6.70 mol of Na and 3.20 mol of Cl_2.

Step 1. What is the limiting reagent?

HAVE → NEED

6.70 mol Na | 1 mol Cl_2 / 2 mol Na → [ ]

3.20 mol Cl_2 | 2 mol Na / 1 mol Cl_2 → [ ]

$2Na + Cl_2 \rightarrow 2NaCl$

Given 6.70 mol of Na and 3.20 mol of Cl_2.

Step 2: What is the excess reagent and how much excess is there?

Sodium: 6.70 moles - 6.40 moles= | 0.3 moles in Excess

$2Na + Cl_2 \rightarrow 2NaCl$

LR determines
Product made

Given 6.70 mol of Na and 3.20 mol of Cl_2.

Step 3. How many moles of NaCl are made?

3.20 mol Cl_2	2 mol NaCl
	1 mol Cl_2

Example #2: $2Cu + S \rightarrow Cu_2S$

Given 80.0 g of copper and 25.0 g of sulfur.

Step 1. What is the limiting reagent?

HAVE				NEED
80.0 g Cu	1 mol Cu	1 mol S	32 g S	
	64 g Cu	2 mol Cu	1 mol S	
25.0 g S	1 mol S	2 mol Cu	64 g Cu	
	32 g S	1 mol S	1 mol Cu	

$2Cu + S \rightarrow Cu_2S$

Given 80.0 g of copper and 25.0 g of sulfur.

Step 2: What is the excess reagent and how much excess is there?

Sulfur: 25.0 grams - 20.0 grams= 5.0 grams in Excess

$2Cu + S \rightarrow Cu_2S$

Given 80.0 g of copper and 25.0 g of sulfur.

Step 3. How much Cu_2S can be made?

80.0 g Cu	1 mol Cu	1 mol Cu_2S	160 g Cu_2S
	64 g Cu	2 mol Cu	1 mol Cu_2S

This answer should be in scientific notation...

Example #3: $N_2 + 3H_2 \rightarrow 2NH_3$

Given 341.0-L of N_2 and 236.0 -L of H_2 @ STP

Step 1. What is the limiting reagent?

HAVE				NEED
341.0 L N_2	1 mol N_2	3 mol H_2	22.4 - L	
	22.4 - L	1 mol N_2	1 mol H_2	
236.0 L H_2	1 mol H_2	1 mol N_2	22.4 - L	
	22.4 - L	3 mol H_2	1 mol N_2	

$N_2 + 3H_2 \rightarrow 2NH_3$

Given 341.0-L of N_2 and 236.0 -L of H_2 @ STP

Step 2: What is the excess reagent and how much excess is there?

Nitrogen: 341.0 liters - 78.67 liters= 262.3 liters in Excess

$N_2 + 3H_2 \rightarrow 2NH_3$

Given 341.0- L of N_2 and 236.0 -L of H_2 @ STP

Step 3. How many grams of NH_3 can be made?

$$\frac{236.0\text{ L } H_2}{22.4\text{ - L}} \left| \frac{1\text{ mol } H_2}{3\text{ mol } H_2} \right| \frac{2\text{ mol } NH_3}{1\text{ mol } NH_3} \left| \frac{17\text{-g } NH_3}{} \right.$$

This answer should be in scientific notation...

Example #4: $N_2 + 3H_2 \rightarrow 2NH_3$

How many liters of NH_3 are produced if 85.0-grams of N_2 and 85.0-grams of H_2 react @ STP?

$$\frac{85.0\text{-g } N_2}{28\text{-g } N_2} \left| \frac{1\text{ mol } N_2}{1\text{ mol } N_2} \right| \frac{3\text{ mol } H_2}{1\text{ mol } H_2} \left| \frac{2\text{-g } H_2}{} \right.$$

$$\frac{85.0\text{-g } H_2}{2\text{-g } H_2} \left| \frac{1\text{ mol } H_2}{3\text{ mol } H_2} \right| \frac{1\text{ mol } N_2}{1\text{ mol } N_2} \left| \frac{28\text{-g } N_2}{} \right.$$

$$\frac{85.0\text{-g } N_2}{28\text{-g } N_2} \left| \frac{1\text{ mol } N_2}{1\text{ mol } N_2} \right| \frac{2\text{ mol } NH_3}{1\text{ mol } NH_3} \left| \frac{22.4\text{ - L}}{} \right.$$

12.4 Percent Yield

- **Theoretical yield**: the maximum amount of product that can form from the amount of reactants given.
  > *(Regular Stoichiometry)*
- **Actual yield**: the amount of product that actually forms during a reaction. Cannot be greater than the theoretical yield.
  > *(Often less)*
- **Percent yield**: a percentage comparing the actual yield with the theoretical yield. *(Same units)* How efficient a reaction is...
  > % = (Actual ÷ Theoretical) x 100

Determining Percent Yield

$CaCO_3 \rightarrow CaO + CO_2$

24.8 g of calcium carbonate is heated to produce an actual yield of 13.1 g of calcium oxide.

1. What is the theoretical yield?

$$\frac{24.8\text{ g } CaCO_3}{100\text{-g}} \left| \frac{1\text{ mol } CaCO_3}{1\text{ mol } CaCO_3} \right| \frac{1\text{ mole CaO}}{1\text{ mol CaO}} \left| \frac{56\text{-g}}{} \right.$$

13.9 g CaO

Determining Percent Yield

$CaCO_3 \rightarrow CaO + CO_2$

24.8 g of calcium carbonate is heated to produce an actual yield of 13.1 g of calcium oxide.

2. What is the percent yield? *(Must be same units!!)*

$$\frac{\text{Actual Yield}}{\text{Theoretical Yield}} \quad \frac{13.1\text{ - g}}{13.9\text{ - g}} \times 100 =$$

94.2 %

Determining Percent Yield

$2CuCl + H_2S \rightarrow Cu_2S + 2HCl$

44.0 mol of CuCl forms an actual yield of 6.0 mol of Cu_2S

1. Theoretical yield of Cu_2S in grams?

$$\frac{44.0\text{ mol CuCl}}{2\text{ mol CuCl}} \left| \frac{1\text{ mol } Cu_2S}{1\text{ mol } Cu_2S} \right| \frac{160\text{-g}}{} \left.$$

Determining Percent Yield

$2CuCl + H_2S \rightarrow Cu_2S + 2HCl$

44.0 mol of CuCl forms an actual yield of 6.0 mol of Cu_2S

2. Actual yield of Cu_2S in grams?

$$\frac{6.0 \text{ mol } Cu_2S}{1 \text{ mol } Cu_2S} \left| \frac{160\text{-g}}{} \right.$$

$2CuCl + H_2S \rightarrow Cu_2S + 2HCl$

44.0 mol of CuCl forms an actual yield of 6.0 mol of Cu_2S

3. What is the percent yield of Cu_2S? *(same units!)*

$$\frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100 =$$

$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$

9.0 g of NH_3 produces a percent yield of 63% water.

1. Theoretical yield of H_2O in grams?
2. Actual yield of H_2O in grams?
Hint: Actual ÷ Theoretical = .63

$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$

1. What is the theoretical yield of H_2O in grams?

$$\frac{9.0 \text{ g } NH_3}{} \left| \frac{1 \text{ mol } NH_3}{17\text{-g}} \right. \left| \frac{6 \text{ mol } H_2O}{4 \text{ mol } NH_3} \right. \left| \frac{18\text{-g}}{1 \text{ mol } H_2O} \right.$$

2. What is the actual yield of H_2O *(in grams)* if only 63% was actually produced?