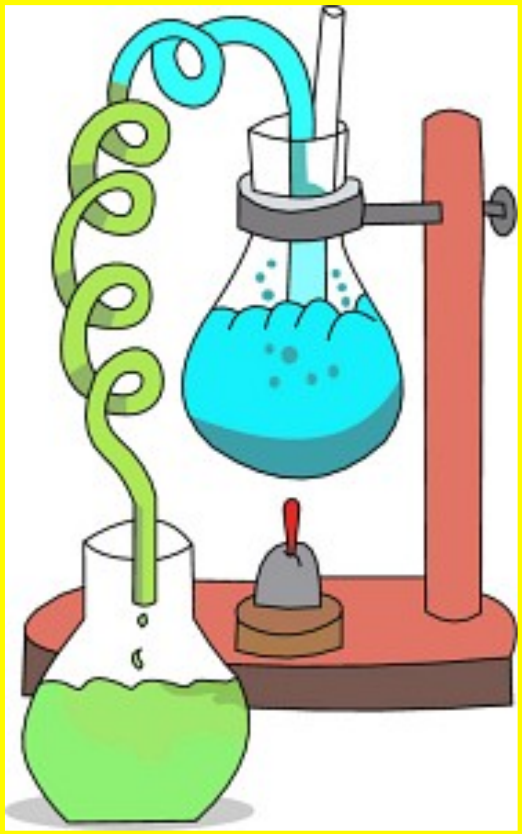
Chapter 9
“STOICHIOMETRY”



Section 9.1
The Arithmetic of Equations

- **OBJECTIVE**
  - Calculate the amount of reactants required or product formed in a nonchemical process.

Section 9.1
The Arithmetic of Equations

- **OBJECTIVE:**
  - Interpret balanced chemical equations in terms of moles, representative particles, mass, and gas volume at STP.

Section 9.1
The Arithmetic of Equations

- **OBJECTIVE:**
  - Identify the quantities that are always conserved in chemical reactions.

Stoichiometry is somewhat like a recipe when Cooking

- When baking, a recipe is usually used, telling the exact amount of each ingredient.
  - If you need more, you can double or triple the amount
- Thus, a **recipe** is much like a **balanced equation**.

Stoichiometry is…

- Greek for "measuring elements"

Pronounced "stoy kee ahm uh tree"

- Defined as: calculations of the *quantities* in chemical reactions, based on a balanced equation.
- There are 4 ways to interpret a balanced chemical equation

#1. In terms of **Particles**

- Element= made of **atoms**
- Molecular compound (made of only nonmetals) = **molecules**
- Ionic Compounds (made of a metal and nonmetal parts) = **formula units** (ions)

$$2H_2 + O_2 \rightarrow 2H_2O$$

- Two molecules of hydrogen and one molecule of oxygen form two molecules of water.
- $2\ Al_2O_3 \rightarrow 4Al + 3O_2$

$$2 \text{ formula units } Al_2O_3 \text{ form } 4 \text{ atoms Al}$$

$$\text{and } 3 \text{ molecules } O_2$$

Now try this: $2Na + 2H_2O \rightarrow 2NaOH + H_2$

#2. In terms of **Moles**

- $2\ Al_2O_3 \rightarrow 4Al + 3O_2$
- $2Na + 2H_2O \rightarrow 2NaOH + H_2$
- The coefficients tell us how many moles of each substance
- A balanced equation is a **Molar Ratio**

#3. In terms of **Mass**

- The Law of Conservation of Mass applies
- We can check using moles
- $2H_2 + O_2 \rightarrow 2H_2O$

$$2 \text{ moles } H_2 \left(\frac{2.02 \text{ g } H_2}{1 \text{ mole } H_2} \right) = 4.04 \text{ g } H_2$$

+

$$1 \text{ mole } O_2 \left(\frac{32.00 \text{ g } O_2}{1 \text{ mole } O_2} \right) = 32.00 \text{ g } O_2$$

36.04 g $H_2 + O_2$

In terms of Mass

- $2H_2 + O_2 \rightarrow 2H_2O$

$$2 \text{ moles } H_2O \left(\frac{18.02 \text{ g } H_2O}{1 \text{ mole } H_2O} \right) = 36.04 \text{ g } H_2O$$

$$2H_2 + O_2 \rightarrow 2H_2O$$

$$\mathbf{36.04} \text{ g } H_2 + O_2 = \mathbf{36.04} \text{ g } H_2O$$

The mass of the reactants equals the mass of the products.

#4. In terms of **Volume**

- At STP, 1 mol of any gas = 22.4 L
- $2H_2 + O_2 \rightarrow 2H_2O$
- $(2 \times 22.4\ L\ H_2) + (1 \times 22.4\ L\ O_2) \rightarrow (2 \times 22.4\ L\ H_2O)$
- NOTE: **mass and atoms** are **ALWAYS** conserved - however, molecules, formula units, moles, and volumes will not necessarily be conserved!

Practice

- Show that the following equation follows the Law of Conservation of Mass (show the atoms balance, and the mass on both sides is equal)

$$2\,Al_2O_3 \rightarrow 4Al + 3O_2$$

Section 9.2
Chemical Calculations

- **OBJECTIVE**
  - Construct mole ratios from balanced chemical equations, and apply these ratios in mole-mole stoichiometric calculations.

Section 9.2
Chemical Calculations

- **OBJECTIVE**
  - Calculate stoichiometric quantities from balanced chemical equations using units of moles, mass, representative particles, and volumes of gases at STP.

Mole to Mole conversions

- $2\ Al_2O_3 \rightarrow 4Al + 3O_2$
  - each time we use 2 moles of Al_2O_3 we will also make 3 moles of O_2

$$\left(\frac{2\text{ moles }Al_2O_3}{3\text{ mole }O_2}\right) \quad \text{or} \quad \left(\frac{3\text{ mole }O_2}{2\text{ moles }Al_2O_3}\right)$$

These are the two possible **conversion factors**

Mole to Mole conversions

- How many moles of O_2 are produced when 3.34 moles of Al_2O_3 decompose?
- $2\ Al_2O_3 \rightarrow 4Al + 3O_2$

$$3.34\ \text{mol}\ Al_2O_3 \left(\frac{3\ \text{mol}\ O_2}{2\ \text{mol}\ Al_2O_3} \right) = 5.01\ \text{mol}\ O_2$$

Practice:

$$2C_2H_2 + 5\ O_2 \rightarrow 4CO_2 + 2\ H_2O$$

- If 3.84 moles of C_2H_2 are burned, how many moles of O_2 are needed?(9.6 mol)

- How many moles of C_2H_2 are needed to produce 8.95 mole of H_2O? (8.95 mol)

- If 2.47 moles of C_2H_2 are burned, how many moles of CO_2 are formed? (4.94 mol)

How do you get good at this?

Practice!!

Calculating Stoichiometric Problems

1. Balance the equation.
2. Convert mass in grams to moles.
3. Set up mole ratios.
4. Use mole ratios to calculate moles of desired chemical.
5. Convert moles back into grams, if necessary.

Mass-Mass Problem:

6.50 grams of aluminum reacts with an excess of oxygen. How many grams of aluminum oxide are formed?

$$4\,Al + 3\,O_2 \rightarrow 2Al_2O_3$$

6.50 ~~g Al~~	1 ~~mol Al~~	2 ~~mol Al~~$_2$O$_3$	101.96 g Al_2O_3	= ? g Al_2O_3
	26.98 ~~g Al~~	4 ~~mol Al~~	1 ~~mol Al~~$_2$O$_3$	

(6.50 x 2 x 101.96) ÷ (26.98 x 4) = 12.3 g Al_2O_3

Another example:

- If 10.1 g of Fe are added to a solution of Copper (II) Sulfate, how much solid copper would form?
- $2Fe + 3CuSO_4 \rightarrow Fe_2(SO_4)_3 + 3Cu$

Answer = 17.2 g Cu

Volume-Volume Calculations:

- How many liters of CH_4 at STP are required to completely react with 17.5 L of O_2 ?
- $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

$$17.5 \text{ L } O_2 \left(\frac{1 \text{ mol } O_2}{22.4 \text{ L } O_2}\right)\left(\frac{1 \text{ mol } CH_4}{2 \text{ mol } O_2}\right)\left(\frac{22.4 \text{ L } CH_4}{1 \text{ mol } CH_4}\right)$$

$$= 8.75 \text{ L } CH_4$$

Notice anything concerning these two steps?

Avogadro told us:

- Equal volumes of gas, at the same temperature and pressure contain the same number of particles.
- Moles are numbers of particles
- You can treat reactions as if they happen liters at a time, as long as you keep the temperature and pressure the same.

1 mole = 22.4 L @ STP

Shortcut for Volume-Volume:

- How many liters of CH_4 at STP are required to completely react with 17.5 L of O_2?
- $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

$$17.5\ L\ O_2 \left(\frac{1\ L\ CH_4}{2\ L\ O_2}\right) = 8.75\ L\ CH_4$$

Note: This <u>only</u> works for Volume-Volume problems.

Section 9.3
Limiting Reagent & Percent Yield

- **OBJECTIVE:**
  - Identify the limiting reagent in a reaction.

Section 9.3
Limiting Reagent & Percent Yield

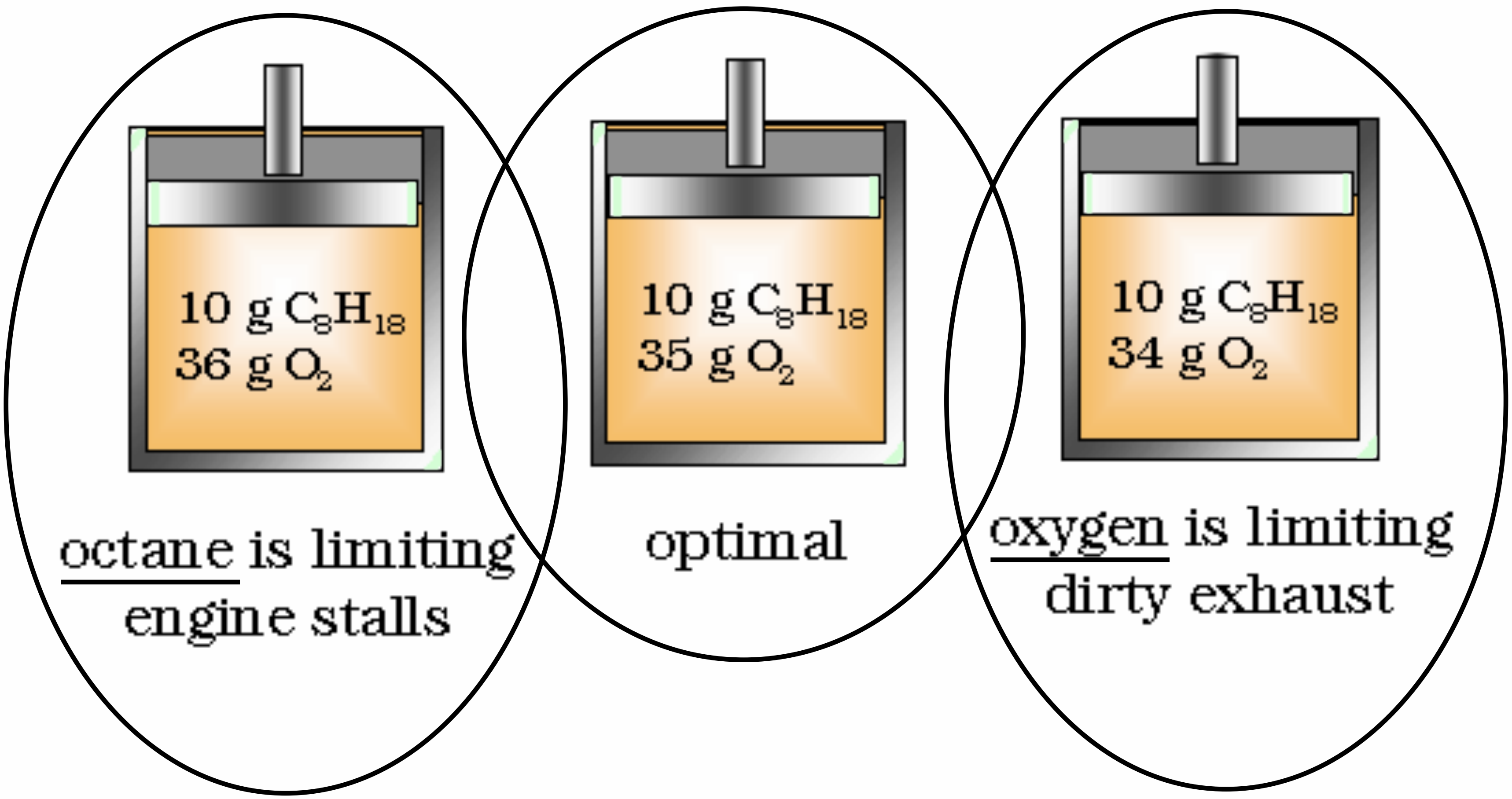
- **OBJECTIVE:**
  - Calculate theoretical yield, percent yield, and the amount of excess reagent that remains unreacted given appropriate information.

“Limiting” Reagent

- If you are given one dozen loaves of bread, a gallon of mustard, and three pieces of salami, how many salami sandwiches can you make?
- The *limiting reagent* is the reactant you run out of first.
- The *excess reagent* is the one you have left over.
- The limiting reagent determines how much product you can make

Limiting Reagents

$$2\ C_8H_{18}(l) + 25\ O_2(g) = 16\ CO_2(g) + 18\ H_2O(l)$$



How do you find out which is limited?

- Do two stoichiometry problems.
- The one that makes the least amount of product is the limiting reagent.

- If 10.6 g of copper reacts with 3.83 g sulfur, how many grams of product (copper (I) sulfide) will be formed?
- $2Cu + S \rightarrow Cu_2S$

Cu is Limiting Reagent

$$10.6\text{ g Cu}\left(\frac{1\text{ mol Cu}}{63.55\text{g Cu}}\right)\left(\frac{1\text{ mol }Cu_2S}{2\text{ mol Cu}}\right)\left(\frac{159.16\text{ g }Cu_2S}{1\text{ mol }Cu_2S}\right)$$

$= 13.3\text{ g }Cu_2S$

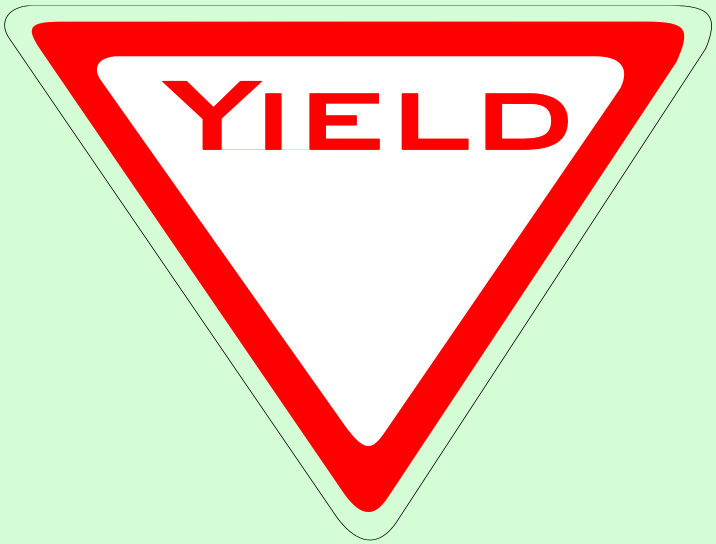
$$3.83\text{ g S}\left(\frac{1\text{ mol S}}{32.06\text{g S}}\right)\left(\frac{1\text{ mol }Cu_2S}{1\text{ mol S}}\right)\left(\frac{159.16\text{ g }Cu_2S}{1\text{ mol }Cu_2S}\right)$$

$= 19.0\text{ g }Cu_2S$

Another example:

- If 10.3 g of aluminum are reacted with 51.7 g of $CuSO_4$ how much copper (grams) will be produced?
- How much excess reagent will remain?

The Concept of:



A little different type of yield than you had in Driver's Education class.

What is Yield?

- The amount of product made in a chemical reaction.
- There are three types:

1. Actual yield- what you get in the lab when the chemicals are mixed
2. Theoretical yield- what the balanced equation tells ***should*** be made
3. **Percent yield** = $\frac{\text{Actual}}{\text{Theoretical}}$ **x 100 %**

Example:

- 6.78 g of copper is produced when 3.92 g of Al are reacted with excess copper (II) sulfate.
- $2Al + 3\ CuSO_4 \rightarrow Al_2(SO_4)_3 + 3Cu$
- What is the actual yield?
- What is the theoretical yield?
- What is the percent yield?

Details on Yield:

- Percent yield tells us how “efficient” a reaction is.
- Percent yield can not be bigger than 100 %.
- Theoretical yield will <u>always</u> be larger than actual yield!
  - Due to impure reactants; competing side reactions; loss of product in filtering or transferring between containers; measuring

End of Chapter 9