AP Chemistry
Ms. Ye

Name _____
Date _____ Block ____

Combustion Analysis

How can burning a substance help determine the substance's chemical formula?

Why?

Scientists have many techniques to help them determine the chemical formula or structure of an unknown compound. One commonly used technique when working with carbon-containing compounds is combustion analysis. Any compound containing carbon and hydrogen will burn. With an ample oxygen supply, the products of the combustion will be carbon dioxide and water. Analyzing the mass of CO_2 and H_2O that are produced allows chemists to determine the ratios of elements in the compound.

Model 1 – Combustion Reactions

$$CH_4 + O_2 \rightarrow CO_2 + H_2O$$

$$C_2H_4 + O_2 \rightarrow CO_2 + H_2O$$

$$C_3H_8 + O_2 \rightarrow CO_2 + H_2O$$

Use Model 1 to answer the following questions

1. What ***reactant*** is always required for combustion?

2. Balance the reactions above by placing the proper coefficients in front of each reactant or product.

3. Analyze the balanced equations for the 4 combustion reactions above.

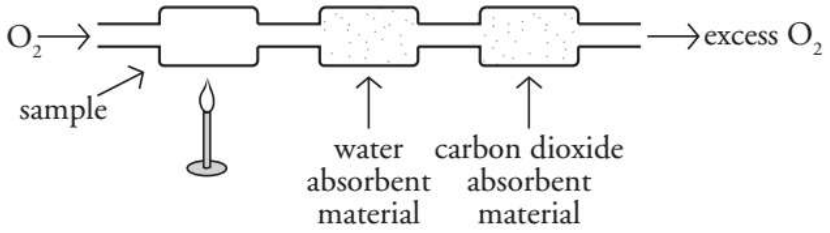
a. How is the coefficient of CO_2 related to the chemical formula of the hydrocarbon being analyzed?

b. If you know the number of moles of CO_2 that are formed from the combustion reaction, what can you determine regarding the number of moles of carbon in the hydrocarbon that was combusted?

c. How is the coefficient of H_2O relate to the chemical formula of the hydrogen carbon being analyzed?

d. If you know the number of moles of H_2O that are formed from the combustion reaction, what can you determine regarding the number of moles of hydrogen in the hydrocarbon that was combusted?

Read This!



In a combustion analysis experiment, a hydrocarbon sample is heated in a stream of oxygen gas. As the sample burns, water and carbon dioxide is pushed through a series of chambers with materials that absorb each of the respective products. The chambers are each weighed before and after the combustion to determine the mass of each product.

Model 2 – Combustion Analysis of C_xH_y Unknowns

Mass of CO_2 produced	Moles of CO_2 produced	Moles of C atoms in unknown	Mass of H_2O produced	Moles of H_2O produced	Moles of H atoms in unknown	C : H atoms in unknown	Empirical Formula of Unknown
27.42 g			22.46 g				

4. The table above shows some data from a combustion analysis experiment. Calculate the following values and put them in the table:

a. The number of moles of CO_2 produced

b. The number of moles of carbon atoms in the unknown hydrocarbon (refer to 3b)

c. The number of moles of H_2O produced

d. The number of moles of hydrogen atoms in the unknown hydrocarbon (refer to 3d).

5. Determine the ratio of carbon to hydrogen atoms and the empirical formula of your unknown.

6. What other information would you need to determine the ***molecular*** formula of the unknown?

Read This!

When the combustion analysis unknown is a compound containing only carbon and hydrogen, all of the atoms in the sample end up in either the CO_2 or H_2O products. However, if the unknown contains other elements, like oxygen or nitrogen, those atoms might end up in the CO_2 and H_2O products (in the case of oxygen) or they might form other gases that move through the apparatus without being captured. Additionally, O atoms may come from the atmosphere as opposed to the combusting sample. Moles of these atoms cannot be calculated by stoichiometry directly. Instead, we must use the law of conservation of mass.

Model 3 – Combustion Analysis of $C_xH_yO_z$ Unknowns (10.00-g samples)

Mass of CO_2 produced	Moles of Carbon atoms in unknown	Mass of H_2O produced	Moles of Hydrogen atoms in unknown	Total Mass of C and H atoms in unknown	Mass of O atoms in unknown	Moles of O atoms in unknown	Empirical Formula of Unknown
19.10 g		11.73 g					

7. The table above shows some data from a combustion analysis experiment that involved a hydrocarbon containing oxygen. Calculate the following values and put them in the table.

a. The number of moles of carbon atoms in the unknown hydrocarbon

b. The number of moles of hydrogen atoms in the unknown hydrocarbon.

8. Using your values from the question above, find the total number of grams of carbon and hydrogen atoms in your unknown.

9. Since your unknown was a 10 gram sample, use your answer from the question above to find the total mass of oxygen atoms in the unknown.

10. Determine the number of moles of Oxygen atoms in your unknown.

11. Determine the simplest ratio of carbon to hydrogen to oxygen atoms and the empirical formula of your unknown hydrocarbon.

Combustion Analysis Practice Problems

1. A 1.50 g sample of an unknown hydrocarbon (C & H only) undergoes complete combustion to produce 4.40 g of CO_2 and 2.70 g of H_2O. Determine the empirical formula of the compound.

2. A 0.250 g sample of an unknown hydrocarbon (C & H only) undergoes complete combustion to produce 0.845 g of CO_2 and 0.173 g of H_2O. Determine the empirical formula of the compound.

3. A 0.2500 g sample of a compound containing carbon, hydrogen and oxygen undergoes complete combustion to produce 0.3664 g of CO_2 and 0.1500 g of H_2O. Determine the empirical formula of the compound.

4. Quinone, which is used in the dye industry and in photography, is an organic compound containing only Carbon, Hydrogen, and Oxygen. It is found that 0.105 g of the compound yields 0.257 g of CO_2 and 0.0350 g of H_2O when completely combusted.

a. Determine the empirical formula of Quinone.

b. Given a molecular weight of approximately 108 g/mol, what is Quinone's molecular formula?

STOICHIOMETRY REVIEW

***Hints:

- Start with your "given" value and convert to the substance you're trying to find
- Include your units when setting up the dimensional analysis problem
- Remember, the **coefficients** in the balanced equation tells you the relative number of **moles** of substance

Use the following equation for solving all problems: **4 Al + 3 O_2 ----> 2 Al_2O_3**

1) If 74.00 grams of Al were burned in excess oxygen, how many grams of Al_2O_3 would be produced?

Given | convert to moles | use balanced equation | convert to grams

X ____/____ X ____/____ X ____/____ =

2) If you had 64.00 grams of O_2, how many grams of Al would be needed to react with that oxygen?

3) If you wanted to produce 4.00 grams of Al_2O_3 how many grams of O_2 would be needed for the reaction?

Answers:

1) 139.8 grams Al_2O_3 2) 71.95 grams Al 3) 1.88 grams O_2

Limiting Reactant & Percent Yield

% yield = $\frac{\text{actual yield}}{\text{theoretical yield}}$ x 100

Theoretical yield = smallest mass **calculated** from the mass of two reactants
Actual yield = mass obtained from an **experiment** (will be given in a word problem)

1. Determine the % yield based on the following information:

a) actual yield = 33.5g,
theoretical yield = 40.0g

b) actual yield = 1.45g,
theoretical yield = 2.04g

2. Acrylonitrile, C_3H_3N, is the starting material for the production of a kind of synthetic fiber acrylic and can be made by the reaction: **$4\ C_3H_6 + 6\ NO \rightarrow 4\ C_3H_3N + 6\ H_2O + 1\ N_2$**

a) What mass of C_3H_3N can be made from 21.6g of C_3H_6?

Given | convert to moles | use balanced equation | convert to grams

X ____/____ X ____/____ X ____/____ =

b) What mass of C_3H_3N can be made from 21.6g of nitrogen monoxide?

Given | convert to moles | use balanced equation | convert to grams

X ____/____ X ____/____ X ____/____ =

c) What is the theoretical yield? (the smallest mass from either a) or b)

d) If the quantities in a & b are combined, identify the limiting reactant and excess reactant

e) If 23.5g of C_3H_3N is *actually* made in this process, what is the % yield?

Limiting Reactant, Theoretical & Percent Yield Practice

1) *Copper (II) chloride reacts with sodium nitrate to produce copper (II) nitrate and sodium chloride:*

____$CuCl_2$ + ____$NaNO_3$ → ____$Cu(NO_3)_2$ + ____NaCl

a) Balance the equation for the reaction given above:

b) If 20 grams of copper (II) chloride react with 20 grams of sodium nitrate, how much sodium chloride can be formed?

c) Identify your limiting and excess reactants.

d) If 11.3 grams of sodium chloride are formed in the reaction, what is the percent yield of this reaction?

2) When lead (II) nitrate reacts with sodium iodide, sodium nitrate and lead (II) iodide are formed.

____$Pb(NO_3)_{2\,(aq)}$ + ____ $NaI_{\,(aq)}$ → ____$PbI_{2\,(s)}$ + ____$NaNO_{3\,(aq)}$

a) Balance the equation for the reaction given above.

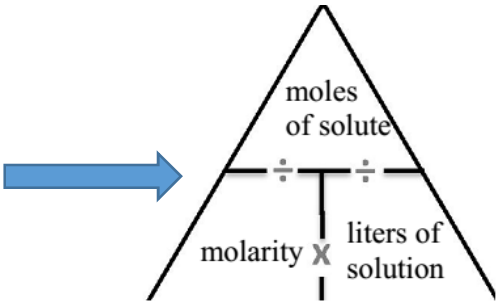
b) If I start with 25.0 grams of lead (II) nitrate and 15.0 grams of sodium iodide, how many grams of sodium nitrate can be formed?

c) Identify your limiting and excess reactants.

d) If 6 grams of sodium nitrate are formed in the reaction described, what is the percent yield of this reaction?

Molarity Review; Solution Stoichiometry

$$\text{molarity} = \frac{\text{moles of solute}}{\text{liter of solution}}$$



Using the Molarity Formula Review:

1. How many moles are in a 2.00 L solution of 1.5 M Sodium hydroxide?
2. How many moles are in 150 mL of 2.50 M Hydrochloric acid?

Stoichiometry Problems With Molarity: **<u>Find the number of moles first!</u>**

1. Using the chemical reaction below, 250 mL of a 3.50 M solution of hydrochloric acid is neutralized with copious amounts of sodium hydroxide to form sodium chloride salt and water. Assuming that the water is boiled off, how many grams of the sodium chloride salt do we expect to form?

$$1\ HCl\ (aq) + 1\ NaOH\ (aq) \rightarrow 1\ NaCl\ (aq) + 1\ H_2O\ (l)$$

 # moles of hydrochloric acid =

Given | use balanced equation | convert to grams

$$X \quad \frac{\qquad}{\qquad} \quad X \quad \frac{\qquad}{\qquad} \quad =$$

2. Using the chemical reaction below, 100 mL of a 1.25M solution of Sodium Sulfate was reacted with excess amounts magnesium hydroxide. How many grams of sodium hydroxide is expected to form? $1\ Na_2SO_4\ (aq) + 1\ Mg(OH)_2\ (aq) \rightarrow 1\ MgSO_4\ (aq) + 2\ NaOH\ (aq)$

3. Using the chemical reaction below, 125 mL of a 2.75M solution of potassium permanganate was reacted with excess amounts of silver nitrate. How many grams of potassium nitrate is expected to form? $1\ KMnO_4\ (aq) + 1\ AgNO_3\ (aq) \rightarrow 1\ KNO_3\ (aq) + 1\ AgMnO_4\ (aq)$