The Fundamentals and Stoichiometry Recitation Worksheet

Week of 25 August 2008.

Fundamental Principles and Terminology

Avogadro's Number: Used to represent the amount of a given atom as a basis for comparison with other atoms. Atoms have different masses because they have differing numbers of electrons, protons, and neutrons; therefore, atoms cannot be compared directly. This measure takes into account this differing number allowing for a comparison of the relative number of atoms.

$$1 \text{ mole} = 6.022 \times 10^{23} \text{ molecules}$$

Atomic Weight: Each atom has a specific weight based upon the number of protons, electrons, and neutrons. The atomic weights of each atom were determined using Carbon-12 as a comparison. The weights reported on the periodic table are actually weighted atomic masses because of the presence of isotopes (variations of atoms with the same number of protons and electrons, but a different number of neutrons). The atomic weights of each atom are used to determine the formula weight or molecular weight of chemical compounds.

Weighted Atomic Mass = (Isotope 1)*(Percent Abundance) + (Isotope 2)*(Percent Abundance) + (Isotope 3)*(Percent Abundance) + ... + (Isotope n)*(Percent Abundance)

Formula Weight: Used to present the number of grams in one mole of an ionic compound. This is the combined sum of all of the atomic masses of the atoms and their relative proportions.

		Atom	No.	Weight of Atom	Combined Weight
Example:	Na_2CO_3	Na atoms	2	23.00 g	46.00 g
		C atoms	1	12.011 g	12.011 g
		O atoms	3	16.00 g	48.00 g
		SUM			106.01 g

Therefore, the formula weight for one mole is 106.01 g. Generally, the formula weights are written in g/mol. Thus, for Na_2CO_3 the formula weight is 106.01 g/mol.

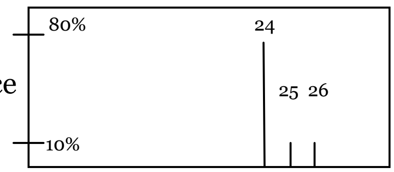
Molecular Weight: The same as formula weight but specific to covalent compounds. Covalently bonded atoms are often called molecules.

Empirical Formulas: Used to describe the relative ratio of atoms in molecules. For example, given the carbohydrate glucose, $C_6H_{12}O_6$, the relative ratio is 1:2:1; therefore, the empirical formula is CH_2O.

Mass Spectrometry: An experimental technique that is used to determine the atomic weight of atoms or the weight of compounds and molecules. This technique can be used to determine the relative abundance of isotopes as well.

Sample Mass Spectrum for Magnesium atoms:

Relative Abundance



Weight

Weighted Atomic Mass/Weight for Magnesium = 24(0.8) + 25(0.1) + 26(0.1) = 24.3 g/mol

Combustion Analysis/Elemental Analysis: This is a technique used to determine the relative percentage of each atom. For example, given Na_2CO_3, the percent composition as indicated with elemental analysis would be as follows:

(Atomic Contribution)/(Formula Weight) * 100% = Percent Composition

Na atoms: 46.00/106.01 * 100% = 43.39%

C atoms: 12.01/106.01 * 100% = 11.32%

O atoms: 48.00/106.01 * 100% = 45.28%

For some problems, the chemical formula may not be known. In such instances, a mass spectrum and the percent composition may be given. As an example, consider the following:

Percent Carbon: 40.0% *Molecular Weight: 180 g/mol*

Percent Oxygen: 53.3%

Percent Hydrogen: 6.7%

To compute the molecular formula:

Number of Carbon Atoms = (180 g/mol)*(0.40)/(12.01 g/mol) = 6 (round to a whole no.)

Number of Oxygen Atoms = (180 g/mol)*(0.533)/(16.00 g/mol) = 6

Number of Hydrogen Atoms = (180 g/mol)*(0.067)/(1.008 g/mol) = 12

Molecular Formula ➔ $C_6H_{12}O_6$

<u>Mole Ratios</u>: The mole ratio is the relative ratio of the components. Balanced chemical equations are often used to represent the mole ratios.

Example: CH_4 (g) + $3O_2$ (g) → CO_2 (g) + $2H_2O$ (g)

Therefore, the mole ratios are as follows:

1 mole CH_4 : 1 mole of CO_2

1 mole of CH_4 : 3 mole of O_2

3 mole of O_2 : 2 mole of H_2O

1 mole of CH_4 : 2 mole of H_2O

If we have, 0.50 moles of CH_4, what are the respective number of moles of the other components?

O_2: (0.50 mole CH_4) x (3 mole of O_2/1 mole of CH_4) = 1.5 mole of O_2

CO_2: (0.50 mole CH_4) x (1 mole of CO_2 / 1 mole of CH_4) = 0.5 mole of CO_2

H_2O: (0.50 mole CH_4) x (2 mole of H_2O / 1 mole of CH_4) = 1.0 mole of H_2O

Using Avogadro's Number, we can also determine the number of molecules given 0.50 moles of CH_4.

Molecules of O_2 =

(0.50 mole CH_4) x (3 mole of O_2 / 1 mole of CH_4) x (6.022 x 10^{23} molecules of O_2 / 1 mole of O_2)

=9.0 x 10^{23} molecules

<u>Limiting Reagent:</u> Most reactions have a reagent that will be depleted first, known as the limiting reagent. These reagents are often limiting because they are available in a small supply or are expensive. The amount of product produced is directly dependent upon the limiting reagent, hence the title. In some instances, it is evident which reagent is limiting; however, it is best to determine the number of possible product moles yielded given the moles of each reagent.

<u>Example 1</u>

Buckminster fullerene is example of an allotrope of carbon. There are three known allotropes of carbon: diamond, graphite, and buckminster fullerene. These differ by their crystal structures. The reactions of fullerenes have been widely studied because they have been identified as possible HIV inhibitors. The most common fullerene has 60 carbons arranged in a "ball" structure and is simply called C_{60}.

Given the following reaction of C_{60} determine the maximum yield of product:

	C_{60} +	$C_5H_8O_4$	→	$C_{65}H_6O_4$
Molecular Weight (g/mol)	720.0	130.0		850.0
Amount Reacted (g)	1.3 x 10^{-3}	3.8 x 10^{-3}		---

$$\left(1.3x10^{-3}\,g\,C_{60}\right)\left(\frac{1\text{ mole of }C_{60}}{720\text{ g }C_{60}}\right)\left(\frac{1\text{ mole }C_{65}H_6O_4}{1\text{ mole of }C_{60}}\right)\left(\frac{850\text{ g }C_{65}H_6O_4}{1\text{ mole }C_{65}H_6O_4}\right)=1.5x10^{-3}\,g\,C_{65}H_6O_4$$

$$\left(3.8x10^{-3}\,g\,C_5H_8O_4\right)\left(\frac{1\text{ mole of }C_5H_8O_4}{130\text{ g }C_5H_8O_4}\right)\left(\frac{1\text{ mole }C_{65}H_6O_4}{1\text{ mole of }C_5H_8O_4}\right)\left(\frac{850\text{ g }C_{65}H_6O_4}{1\text{ mole }C_{65}H_6O_4}\right)=2.5x10^{-2}\,g\,C_{65}H_6O_4$$

Therefore in this reaction, C_{60} is the limiting reagent because it is used up first and yields the smallest amount of product. A maximum product yield is 1.5 x 10^{-3} g for this reaction. *The limiting reagent is always used to determine the possible yield.*

The fullerene reaction is an example of a ***synthesis*** reaction in which two components are combined to form a single product.

Example 2

The following example is an oxidation-reduction process. In this example, zinc is oxidized by the acid because in the process, zinc loses two electrons to become Zn^{2+}. Hydrogen ion is reduced from H^+ to molecular hydrogen which has an oxidation state of 0. It is important to be able to identify the class of chemical reactions. (Review Ch. 4 in detail). Furthermore, the concept of concentration is emphasized in the following example. Concentration defines the number of moles per given volume. Molarity is the most common measure of concentration.
Molarity = **M** = (moles of solute)/(liters of solvent)

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

Oxidation reduction

All acids are dissolved in an aqueous (water) medium. Therefore, hydrochloric acid is composed of hydrogen chloride (solute) dissolved in water (solvent).

Given the following information, determine the theoretical yield in grams of zinc chloride given that 2.9 grams of zinc metal was reacted with 15-mL of 1.1 M HCl.

	Zn (s) +	2HCl (aq)	→	$ZnCl_2$ (aq)	+ H_2 (g)
Formula Weight (g/mol)	65.4	36.45		136.3	2.0

$$(2.9\text{ g Zn})\left(\frac{1\text{ mole of Zn}}{65.4\text{ g Zn}}\right)\left(\frac{1\text{ mole of }ZnCl_2}{1\text{ mole of Zn}}\right)\left(\frac{136.3\text{ g }ZnCl_2}{1\text{ mole of }ZnCl_2}\right) = 6.0\text{ g }ZnCl_2$$

$$(15 - mL\text{ solvent})\left(\frac{1 - L\text{ solvent}}{1000 - mL\text{ solvent}}\right)\left(\frac{1.1\text{ mol HCl}}{1 - L\text{ solvent}}\right)\left(\frac{1\text{ mole }ZnCl_2}{2\text{ mole HCl}}\right)\left(\frac{136.3\text{ g }ZnCl_2}{1\text{ mole }ZnCl_2}\right) = 1.1\text{ g }ZnCl_2$$

In this example, HCl was the limiting reagent and the theoretical yield (maximum amount produced) of zinc chloride was 1.1 g as determined with HCl being the limiting reagent.

Percent Yield

The percent yield is a measure of how good the reaction conditions are for a given reaction. The percent yield compares the actual yield (how much was produced) to the theoretical yield (what should have been produced).

From the examples above, the percent yield would be calculated as follows:

From example 1: If 1.1 x 10^{-4} grams of the derivatized C_{60} molecule is produced the percent yield is:

$$\frac{1.1x10^{-4}g}{1.5x10^{-3}g}x100 = 7.3\%$$

Group Practice Exercises and Problems

1. Bromine has two stable isotopes Br-79 and Br-81. Calculate the percent abundance of each isotope.

2. Determine the number of moles of 44.3 g of $K_2Cr_2O_7$. Determine the number of molecules using Avogadro's number.

3. Given the following combustion reaction, identify the relative percentages expected for each component given that 0.65 moles of C_2H_6O were used for the reaction:

   $C_2H_6O\ (l) + 3O_2\ (g) \rightarrow 2CO_2\ (g) + 3H_2O\ (g)$

_____ mole of O_2	____________________ moles of O_2	_____ g of O_2
_____ mole of CO_2	____________________ moles of CO_2	_____ g of CO_2
_____ mole of H_2O	____________________ moles of H_2O	_____ g of H_2O

4. Elemental analysis of nicotine yields the following percentages: (Carbon, 74%); (Hydrogen, 9%), and (Nitrogen, 17%). Determine the empirical formula and molecular formula for nicotine.

5. Given the following equations, answer the proceeding questions concerning the equations. Note: the equations are NOT balanced.

$AgBr + NaOH + C_6H_6O_2 \rightarrow Ag + H_2O + NaBr + C_6H_4O_2$ (photo dev.)

$NaOH + Cl_2 \rightarrow NaOCl + NaCl + H_2O$ (making bleach)

$Al + Fe_2O_3 \rightarrow Al_2O_3 + Fe$ (thermite reaction)

a. Given that 1.2 grams of Al_2O_3 were synthesized from 2.6 grams of Fe_2O_3 and 2.1 grams of Aluminum, identify the percent yield and limiting reagent.

b. Given that 6 g of silver is produced in the photo development reaction, how many grams of water is produced?

c. Given the production of 6 g of NaOCl in the bleach reaction, what is the minimum number of moles of NaOH used for the reaction. Assume excess chlorine gas.

Individual Practice Exercises and Problems

This must be completed before recitation in order to be admitted in the classroom. These problems should be completed individually in order for you to access your understanding of the material. A group discussion will follow during the next recitation period concerning these problems.

1. Determine the formula weight of Cu_2SO_4. Determine the number of moles and molecules of 1.54 g of Cu_2SO_4.

2. Given the following combustion reaction, identify the relative percentages expected for each component given that 2.41 moles of C_2H_6 were used for the reaction:

   C_3H_6 (g) + (9/2) O_2 (g) → $3CO_2$ (g) + $3H_2O$ (g)

_____	mole of O_2	____________________	moles of O_2	_____	g of O_2
_____	mole of CO_2	____________________	moles of CO_2	_____	g of CO_2
_____	mole of H_2O	____________________	moles of H_2O	_____	g of H_2O

3. The following reaction is used for rocketry:

$$2\ N_2H_4\ (l) + N_2O_4\ (l) \rightarrow 3\ N_2\ (g) + 4H_2O\ (g)$$

A fuel mixture used in the early of rocketry is composed of two liquids, hydrazine (N_2H_4) and dinitrogen tetraoxide (N_2O_4), which ignite to form nitrogen gas and water vapor. How many grams of nitrogen gas form when 1.00×10^2 g of N_2H_4 and 2.00×10^2 g of N_2O_4 are mixed?

4. Maleic acid is an organic compound composed of 41.39% carbon, 3.47% hydrogen, and the rest is oxygen. If 0.129 mol of maleic acid has a mass of 15.0 g, what is the molecular formula