STOICHIOMETRY

Honors Chemistry

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Stoichiometry is the calculation of ____quantities_______ in chemical reactions.

You can imagine chemical equations as the recipe for baking cookies:

200 chocolate chips + 1cup milk + 2cup flour + 4cup sugar → 12 cookies

The recipe tells you how many ____ingredients__ to mix together to make a certain number of cookies.

Ex. If I want to bake 48 cookies, how many chocolate chips would I need to buy at the store?

x chocolate chips= 48 cookies x (200 cc/ 12 cookies)

= 800 chocolate chips

How many cups of milk do I need? How many cups of sugar?

x cups of milk= 48 cookies x (1 cup of milk/ 12 cookies)

= **4 cups of milk**

x cups of sugar= 48 cookies x (4 cups of sugar/ 12 cookies)

= **16 cups of sugar**

Interpreting Chemical Equations:

$$2H_2\,(g) + \_\_\_\_O_2\,(g) \rightarrow 2H_2O\,(g)$$

What are the reactants? _____H_2 and O_2___. This corresponds with

____ingredients_____ from the cookie analogy.

What are the products? ___water_____. This corresponds with

____# cookies_____ from the cookie analogy.

What are the smaller numbers called? ____subscripts____

What are the larger numbers called? ______coefficients_____

Why do we have to balance chemical equations? Law of Conservation of Mass

The ___coefficients___ tell us the number of moles of reactants and products just as they tell us about the amount of ingredients and products in the cookie analogy.

Convert the equation $2H_2 + O_2 \rightarrow 2H_2O$ into words:

Hydrogen gas reacts with oxygen gas and produces water.

What is the ratio of hydrogen to oxygen? __2:1__

What is the ratio of hydrogen to water? ____2:2_____

Ex. $\mathbf{2H_2S\ (g) + 3O_2\ (g) \rightarrow 2SO_2\ (g) + 2H_2O\ (g)}$

Convert the equation into words:

H_2S reacts with oxygen gas and produces SO_2 and water.

What is the ratio of H_2S to H_2O? ___2:2___

What is the ratio of O_2 to SO_2? ____3:2_____

Why do we care about these coefficient ratios?

MOLE:MOLE CALCULATIONS

COMPOUND A **COMPOUND B**

Ex. Write out the conversion from moles of A to moles of B

$2A + 3B \rightarrow 4C$–If I have 1.5 mol of A→ xmol B= 1.5 mol A x (3 mol B/ 2 mol A)= 2.25 mol B

Examples of Mole:Mole Calculations with Real Chemical Equations:

1. Given the formula N_2 (g) + $3H_2$ (g) → $2NH_3$ (g), how many moles of ammonia are produced when 0.60 mol of nitrogen reacts with hydrogen?

X mol NH_3 = .60 mol N_2 x (2 mol NH_3/ 1mol N_2)

= 1.2 mol NH_3

2a. Based on the equation, 4Al (s) + $3O_2$ (g) → $2Al_2O_3$ (s), which represents the formation of aluminum oxide, write the six mole ratios that can be derived from this equation.

4 mol Al/ 2 mol O_2; 4 mol Al/ 2 mol Al_2O_3; 3 mol O_2/ 2 mol Al_2O_3;

2 mol O_2/ 4 mol Al; 2 mol Al_2O_3/ 4 mol Al; 2 mol Al_2O_3/ 3 mol O_2

b. How many moles of aluminum are needed to form 3.7 mol Al_2O_3?

= 7.4 mol

c. How many moles of oxygen are required to react completely with 14.8 mol Al?

= 11.1 mol

d. How many moles of Al_2O_3 are formed when 0.78 mol O_2 reacts with aluminum?

=.52 mol

MASS:MASS CALCULATIONS

COMPOUND A **COMPOUND B**

(Right before the left hand side arrow should be grams of A and right above the left hand side arrow should be 1mol/ Molecular Mass)

(Right above the right hand side arrow should be Molecular Mass/ 1 mol and right after the arrow should be grams of B)

Ex. Write out the conversion from grams of A to grams of B

X grams of B =x grams of Ax(1mol A/ MM of A)x(MolB/MolA Ratio)x(MM of B/1mol B)

Examples of Mass:Mass Calculations with Real Equations:

1. Calculate the number of grams of NH_3 produced by the reaction of 5.40 g of hydrogen with an excess of nitrogen. The balanced equation is

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

Xg NH_3 = 5.4 g H_2 x (1 mol/ 2 g) x (2 mol NH_3/ 3 mol H_2) x (17 g/ 1 mol)

=30.6 g of NH_3

2. Acetylene gas (C_2H_2) is produced by adding water to calcium carbide (CaC_2)

$$CaC_2\ (s) + 2H_2O\ (l) \rightarrow C_2H_2\ (g) + Ca(OH)_2\ (aq)$$

a. How many grams of acetylene are produced by adding water to 5.00 g CaC_2.

=2.03 g

b. How many moles of CaC_2 are needed to react completely with 49.0 g H_2O?

= 1.36 mol

VOLUME:VOLUME CALCULATIONS

COMPOUND A **COMPOUND B**

(Right before the left hand side arrow should be volume of A)

(Right after the arrow should be volume of B)

Ex. Write out the conversion from liters of A to liters of B

Volume A→ Mol A→ Mol B→ Volume B

Examples of Volume:Volume Calculations with Real Equations:

1. Assuming STP, how many liters of oxygen are needed to produce 19.8 L SO_3 according to this balanced equation?

$$2SO_2\ (g) + O_2\ (g) \rightarrow 2SO_3\ (g)$$

x L O_2= 19.8 L SO_3 x (1 mol SO_3/ 22.4L) x (1 mol O_2/ 2 mol SO_3) x (22.4 L/ 1 mol O_2)

=9.9 L O_2

2. The equation for the combustion of carbon monoxide is $2CO\ (g) + O_2\ (g) \rightarrow 2CO_2\ (g)$. How many liters of oxygen are required to burn 3.86 L of carbon monoxide?

=1.93 L

3. Phosphorus and hydrogen can be combined to form phosphine (PH_3).

$$P_4\ (s) + 6H_2\ (g) \rightarrow 4PH_3\ (g)$$

How many liters of phosphine are formed when 0.42 L of hydrogen reacts with phosphorus?

=.28 L

MIX OF PROBLEM TYPES

1. How many molecules of oxygen are produced when a sample of 29.2 g of water is decomposed by electrolysis according to this balanced equation?

$$2H_2O\ (l) \rightarrow 2H_2\ (g) + O_2\ (g)$$

=4.88 x 10^{23}molecules

2. How many molecules of oxygen are produced by the decomposition of 6.54 g of potassium chlorate ($KClO_3$)?

$$2KClO_3\ (s) \rightarrow 2KCl\ (s) + 3O_2\ (g)$$

=4.82 x 10^{22} molecules

3. The last step in the production of nitric acid is the reaction of nitrogen dioxide with water. $3NO_2\ (g) + H_2O\ (l) \rightarrow 2HNO_3\ (aq) + NO\ (g)$. How many grams of nitrogen dioxide must react with water to produce 5.00 x10^{22} molecules of nitrogen monoxide?

=11.46 g

4. Nitrogen monoxide and oxygen gas combine to form brown gas nitrogen dioxide. How many milliliters of nitrogen dioxide are produced when 3.4 mL of oxygen reacts with an excess of nitrogen monoxide? Assume conditions of STP.

$$2NO\ (g) + O_2\ (g) \rightarrow 2NO_2\ (g)$$

xmL NO_2=3.4 mL x (1L/1000mL) x (1mol O_2/22.4L) x (2mol NO_2/1mol O_2) x (22.4L/1mol) x (1000mL/1L)

=6.8mL

5. Consider the equation CS_2 (l) + $3O_2$ (g) → CO_2 (g) + $2SO_2$ (g):

a. Calculate the volume of sulfur dioxide produced when 27.9 mL O_2 reacts with carbon disulfide.

=.0186L

b. How many deciliters of carbon dioxide are produced when 0.38 L SO_2 is formed?

= 1.9 dL

6. Using the following equation:

$$2\ NaOH + H_2SO_4 \rightarrow 2\ H_2O + Na_2SO_4$$

How many grams of sodium sulfate will be formed if you start with 200 grams of sodium hydroxide and you have an excess of sulfuric acid?

=355 g

7. Using the following equation:

$$Pb(SO_4)_2 + 4\ LiNO_3 \rightarrow Pb(NO_3)_4 + 2\ Li_2SO_4$$

How many grams of lithium nitrate will be needed to make 250 grams of lithium sulfate, assuming that you have an adequate amount of lead (IV) sulfate to do the reaction?

=313 grams

8. The incandescent white of a fireworks display is caused by the reaction of phosphorous with O_2 to give P_4O_{10}.

a. Write the balanced chemical equation for the reaction.
$4P + 5O_2 \rightarrow P_4O_{10}$

b. How many grams of O_2 are needed to combine with 6.85g of P?
= 8.8 g

c. How many grams of P_4O_{10} can be made from 8.00g of O_2?
=14.2 g

d. How many grams of P are needed to make 7.46g P_4O_{10}?
= 4.74 g

9. In *dilute* nitric acid, HNO_3, copper metal dissolves according to the following equation: $3Cu(s) + 8HNO_3(aq) \rightarrow 3Cu(NO_3)_2(aq) + 2NO(g) + 4H_2O(aq)$
How many grams of HNO_3 are needed to dissolve 11.45g of Cu?
=30.3 g

10. Lithium hydroxide reacts with hydrobromic acid to produce lithium bromide and water. If you start with ten grams of lithium hydroxide, how many grams of lithium bromide will be produced?
$LiOH + HBr \rightarrow LiBr + H_2O$
=36.25 g

11. Ethylene (C_2H_4) reacts with oxygen gas to produce carbon dioxide and water. If you start with 45 grams of ethylene, how many grams of carbon dioxide will be produced?
$C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$
=141.4 g

LIMITING REAGENT

When we bake our chocolate chip cookies, if we have plenty of flour, sugar, and milk, but not of chocolate chips, the number of ___cookies____ that we can bake is limited by the number of chocolate chips we have.

Therefore, we say that chocolate chips are the ______limiting reagent________

while the other ingredients are the _________excess reagents_________.

Ex. Recipe: 20 chocolate chips, .25 cup of water, .25 cup of flour, 1 tbsp of sugar→ 6 cookies.

If I have 20 chocolate chips, 1 cup of water, flour, and sugar, what is the limiting reagent? Chocolate Chips

If I have .1 cup of water, 20 chocolate chips, and 1 cup of flour and sugar, what is the limiting reagent? How many cookies can I make?

X cookies = .1 cup of water x (6 cookies/.25 cup of water)

= **2.4 cookies**

Definitions:

_____limiting reagent________ limits or determines the amount of product that can be formed in a reaction.

_____excess reagent_______ the reactant that is not completely used up in a reaction.

THE AMOUNT OF PRODUCT CAN BE DETERMINED FROM THE GIVEN AMOUNT OF _____limiting reagent_______.

Ex. Sodium chloride can be prepared by the reaction of sodium metal with chlorine gas.

$$Na\ (s) + Cl_2\ (g) \rightarrow NaCl\ (s)$$

Suppose that 6.70 mol Na reacts with 3.20 mol Cl_2.

a. How many moles of NaCl are produced?

Step 1: Determine whether this is a limiting reagent problem

This is a limiting reagent problem because there are two quantities given to you for the amount of reactant being used. As a result, you must decide which is the limiting reagent.

Step 2: Write a balanced chemical equation

$2Na + Cl_2 \rightarrow 2NaCl$

Step 3: Convert mass of reactants to moles of products

Na: X mol NaCl= 6.7 mol Na x (2 mol NaCl/ 2 mol Na)

=6.7 mol NaCl

Cl_2: X mol NaCl = 3.2 mol Cl_2 x (2 mol NaCl/ 1 mol Cl_2)

= 6.4 mol NaCl

Step 4: Identify the limiting and excess reactants.

Therefore, since Cl_2 produces fewer moles of NaCl, we say that it is the limiting reagent. It limits the number of moles of NaCl that will be produced.

Step 5: Answer the question.

6.4 moles of NaCl are produced.

Practice Problems:

1. The equation for the complete combustion of ethene (C_2H_4) is

$$C_2H_4\ (g) + 3O_2(g) \rightarrow 2CO_2\ (g) + 2H_2O\ (g)$$

If 2.70 mol C_2H_4 is reacted with 6.30 mol O_2:

a. Identify the limiting reagent.

C_2H_4- X mol H_2O = 2.70 mol C_2H_4 x (2 mol H_2O/ 1 mol C_2H_4) = 5.4 mol

O_2- X mol H_2O = 6.3 mol O_2 x (2 mol H_2O/ 3 mol O_2) = 4.2 mol

Therefore, O_2 is your limiting reagent.

b. Calculate the moles of water produced.

4.2 mol of H_2O

2. The equation for the incomplete combustion of ethene (C_2H_4) is

$$C_2H_4\ (g) + 2O_2\ (g) \rightarrow 2CO + 2H_2O\ (g)$$

If 2.70 mol C_2H_4 is reacted with 6.30 mol O_2:

a. Identify the limiting reagent.

C_2H_4

b. Calculate the moles of water produced.

5.4 moles of water

3a. If 2Cu (s) + S (s) → Cu_2S (s), what is the limiting reagent when 80.0 g Cu reacts with 25.0 g S?

Cu →x mol of Cu_2S= 80 g Cu x (1mol Cu/ 63.5 g) x (1 mol Cu_2S/2 mol Cu) = .63 mol

S→ x mol of Cu_2S=25 g S x (1 mol S / 32g) x (1 mol Cu_2S/1 mol S)= .78 mol

Therefore, Cu is the limiting reagent.

b. What is the maximum number of grams of Cu_2S that can be formed?

X g = .63 mol of Cu_2S x (159 g/ mol) = **100.2 g**

4. Hydrogen gas can be produced in the laboratory by the reaction of magnesium metal with hydrochloric acid.

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

a. Identify the limiting reagent when 6.00 g HCl reacts with 5.00 g Mg.

HCl is limiting.

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

HCl will produce .082 mol of H_2. Convert that to grams and you get .164 g.

5. Acetylene (C_2H_2) will burn in the presence of oxygen:

$$2C_2H_2\ (g) + 5O_2\ (g) \rightarrow 4CO_2\ (g) + 2H_2O\ (g)$$

How many grams of water can be produced by the reaction of 2.40 mol C_2H_2 with 7.4 mol O_2?

C_2H_4 is the limiting reagent. As a result, only 2.40 mol of water are produced which means that 43.2 g of water are produced.

PERCENT YIELD:

When an equation is used to calculate the amount of product that will form during a reaction, the ______theoretical yield__ is obtained. This is the maximum amount of __product__ that can be formed from given amounts of reactants. In contrast, the amount of product that actually forms when the reaction is carried out in the laboratory is called the _____actual yield__.

Therefore the Percent Yield = Actual Yield/ Theoretical Yield x 100

It tells us: What percent of our expected amount of product was actually produced. If it is >100% this really doesn't make sense and means that some serious error happened in the experiment. Normally, our percent yield is <100% which means that not as much product was actually produced as what was originally predicted.

Practice Problems:

1. Calcium carbonate is decomposed by heating, as shown below:

$$CaCO_3\ (s) \rightarrow CaO\ (s) + CO_2\ (g)$$

a. What is the theoretical yield of CaO if 24.8 g $CaCO_3$ is heated?

X g CaO = 24.8 g $CaCO_3$ x (1 mol/ 100 g) x (1 mol CaO/ 1 mol $CaCO_3$) x (56g/ 1mol)

= 13.89 g

b. What is the percent yield if 13.1 g CaO is produced?

% yield = Actual Yield/ Theoretical Yield

= 13.1 / 13.89 x 100

=94.3% yield.

2. When 84.8 g of iron (III) oxide reacts with an excess of carbon monoxide, 54.3 g of iron is produced:

$$Fe_2O_3\ (s) + 3CO\ (g) \rightarrow 2Fe\ (s) + 3CO_2\ (g)$$

What is the percent yield of this reaction?

91.48%

3. If 50.0 g of silicon dioxide is heated with an excess of carbon, 27.9 g of silicon carbide is produced:

$$3SiO_2 (s) + 9C(s) \rightarrow 3SiC (s) + 6CO (g)$$

What is the percent yield of this reaction? **83.7 %**

Review Problems:

1. The reaction of powdered aluminum and iron(II)oxide,
   $2Al(s) + Fe_2O_3(s) \rightarrow Al_2O_3(s) + 2Fe(l)$
   produces so much heat the iron that forms is molten. Because of this, railroads use the reaction to provide molten steel to weld steel rails together when laying track. Suppose that in one batch of reactants 4.20mol Al was mixed with 1.75mol Fe_2O_3.
   a. Which reactant, if either, was the limiting reactant?
   Fe_2O_3 is the limiting reactant.
   b. Calculate the mass of iron (in grams) that can be formed from this mixture of reactants.
   279.5 g
2. Silver nitrate, $AgNO_3$, reacts with iron(III) chloride, $FeCl_3$, to give silver chloride, AgCl, and iron(III) nitrate, $Fe(NO_3)_3$. A solution containing 18.0g $AgNO_3$ was mixed with a solution containing 32.4g $FeCl_3$. How many grams of which reactant *remains* after the reaction is over?

$3AgNO_3 + FeCl_3 \rightarrow 3AgCl + Fe(NO_3)_3$

Now find which is limiting:

$AgNO_3 \rightarrow$ X mol AgCl = 18 g $AgNO_3$ x (1 mol $AgNO_3$/ 169.86 g) x (3 mol AgCl/ 3 mol $AgNO_3$) $\rightarrow$ .106 mol of AgCl

$FeCl_3 \rightarrow$ x mol AgCl = 32.4 g $FeCl_3$ x (1 mol $FeCl_3$/ 162.4 g) x (3 mol AgCl/ 1 mol $FeCl_3$) $\rightarrow$ .60 mol of AgCl

Now answer the question. If $AgNO_3$ is your limiting reagent, That means only .106 mol of AgCl were used. As a result, we can determine the number of grams of $FeCl_3$ that were used and then find the amount that was left over. Therefore, lets first use .106mol of AgCl to find out how much of our excess reagent was actually used. X g of $FeCl_3$ = .106 mol AgCl x (1 mol $FeCl_3$/ 3 mol AgCl) x (162.4 g /1 mol $FeCl_3$) $\rightarrow$ 5.74 grams of $FeCl_3$ were actually used. Since you start with 32.4 g, then by calculating 32.4-5.74, you will find the amount of reactant that remains after the reaction is over: **26.7 g**

3. Barium sulfate, $BaSO_4$, is made by the following reaction:

$$Ba(NO_3)_{2(aq)} + Na_2SO_{4(aq)} \rightarrow BaSO_{4(s)} + 2NaNO_{3(aq)}$$

An experiment was begun with 75.00g of $Ba(NO_3)_2$ and an excess of Na_2SO_4. After collecting and drying the product, 63.45g $BaSO_4$ was obtained. Calculate the theoretical yield and percent yield of $BaSO_4$.

94.8%

4. Aluminum sulfate can be made by the following reaction:

$$2AlCl_{3(aq)} + 3H_2SO_{4(aq)} \rightarrow Al_2(SO_4)_{3(aq)} + 6HCl_{(aq)}$$

It is quite soluble in water, so to isolate it the solution has to be evaporated to dryness. This drives off the volatile HCl, but the residual solid has to be treated to a little over 200°C to drive off all the water. In one experiment, 25.0g of $AlCl_3$ was mixed with 30.0g H_2SO_4. Eventually, 28.46g of pure $Al_2(SO_4)_3$ was isolated. Calculate the percent yield.

Must first find the theoretical yield which is .094 mol or 32.148g of $Al_2(SO_4)_3$.

Now find percent yield= **88.5%**

5. Given the equation: $2HCl + Na_2SO_4 \rightarrow 2NaCl + H_2SO_4$

If you start with 20 grams of hydrochloric acid, how many grams of sulfuric acid will be produced? **26.85 g**

6. Propane (C_3H_8) is the fuel used in most gas grills. It burns according to the balanced equation: $C_3H_8 + 5O_2 \rightarrow 4H_2O + 3CO_2$. If you burn 215 g of propane, how many grams of H_2O will be produced?

351.82g

7. The combustion of acetylene gas is represented by this equation:

$$2C_2H_2\ (g) + 5O_2\ (g) \rightarrow 4CO_2\ (g) + 2H_2O\ (g)$$

a. How many grams of CO_2 and grams of H_2O are produced when 52.0 g C_2H_2 burns?

176 g CO_2

36 g H_2O

b. How many grams of oxygen are required to burn 52.0 g C_2H_2?

160g

8. Tin (II) Fluoride, formerly found in many kinds of toothpaste, is formed in this reaction:

$$Sn (s) + 2HF (g) \rightarrow SnF_2 (s) + H_2 (g)$$

a. How many liters of HF are needed to produce 9.40 L H_2 at STP?

18.8 L

b. How many molecules of H_2 are produced by the reaction of tin with 20.0 L HF at STP?

2.69×10^{23} molecules

c. How many grams of SnF_2 can be made by reacting 7.42×10^{24} molecules of HF with tin?

965.7 g

9. 3.64 g of calcium hydroxide react with excess sodium sulfate in aqueous solution to produce solid sulfate and aqueous sodium hydroxide. How many moles of calcium atoms are reacting here?

$Ca(OH)_2(aq) + Na_2SO_4(aq) \rightarrow CaSO_4(s) + 2NaOH(aq)$

A. 0.00982 mol
B. 0.0246 mol
C. 0.0266 mol
D. 0.0491 mol
E. 0.0909 mol

10. A 0.250 M solution of $AgNO_3$ is to be prepared. What mass of solid $AgNO_3$ do you need in order to prepare 50.0 mL of this solution?

A. 2.12 g
B. 4.98 g
C. 6.66 g
D. 9.87 g

E. 12.5 g

11. Which compound has the highest percent by mass of nitrogen?

A. $(CH_3)_3N$(l)
B. N_2O_4(l)
C. HNO_3(g)
D. NO_2(g)
E. N_2(g)

12. If one mole of the rocket fuel ammonium perchlorate, NH_4ClO_4 (s) is allowed to react with excess Al so all of the NH_4ClO_4 is consumed, how many molecules of water will be produced?

$3NH_4ClO_4 (s) + 3Al (s) \rightarrow Al_2O_3 (s) + AlCl_3 (s) + 3NO (g) + 6H_2O (g)$

A. 3.61×10^{23}
B. 1.00×10^{23}
C. 6.02×10^{23}
D. 1.20×10^{24}
E. 3.01×10^{24}

13. How many grams of potassium cyanide, PCl_3, is produced from 93.0 grams of P_4 (s) and 213 g of Cl_2 (g), assuming the reaction goes to completion? The balanced equation for the reaction is:

$P_4 (s) + 6Cl_2 (g) \rightarrow 4PCl_3 (g)$

A. 277 g
B. 416 g
C. 213 g
D. 104 g
E. 69.3 g

14. How many grams of $K_2Cr_2O_7$ (molar mass = 294 g/mol) are required to prepare 200 mL of a 0.100 M solution?

A. 2.94
B. 4.82
C. 5.88
D. 2.94
E. 58.8

15. How many moles of Al_2O_3 are formed when a mixture of 0.36 moles Al and 0.36 moles O_2 is ignited?

A. 0.12
B. 0.18
C. 0.28
D. 0.46
E. 0.72

16. What is the total number of atoms contained in 2.00 moles of nickel?

A. 58.9
B. 118
C. 6.02×10^{23}
D. 1.2×10^{24}
E. 2.4×10^{24}