✳ KEY

Calculations Involving Reactions (Stoichiometry)

(Stoichiometry) It is expected that students will:

1) relate the coefficients in a balanced equation to the relative number of molecules or moles (the mole ratio) of reactants and products in the chemical reaction
2) perform calculations involving reactions using any of the following:
3) number of molecules
4) moles
5) mass
6) gas volume at STP
7) solution concentration and volume
8) perform calculations involving limiting reagent and percent yield

STOICHIOMETRY: the relationship between the amount of reactants used in a chemical reaction and the amounts of products produced in the reaction.

1. The meaning of the coefficients in a reaction equation:

Example: Write a balanced reaction for the combustion of methane, CH_4:

$$1CH_4 + 2O_2 \;\text{------} > 1CO_2 + 2H_2O + 891 \text{ kJ}$$

• This equation indicates that 2 oxygen molecules react with 1 molecule of methane to produce 1 molecule of CO_2 and 2 molecules of water (and 891 kJ of energy).

• The coefficients can refer to the number of molecules (or atoms) or it can also be described in terms of the number of moles.

• The reaction always reacts with the 2 moles of oxygen to 1 mole of methane ratio. So, we can related the amount of oxygen that reacts with the amount of methane needed. That is, for a complete reaction, we need twice as much oxygen as methane.

• We can also relate the amount of the product produced if we know the amount of reactant. If one mole of methane reacts with sufficient oxygen (2 moles), then 1 mole of carbon dioxide and 2 moles of water is produced (and let's not forget the energy produced which is 891kJ).

$$1CH_4 + 2O_2 \;\text{------} > 1CO_2 + 2H_2O + 891 \text{ kJ}$$

Question #1: If 10 molecules of methane reacts with sufficient oxygen, how many water molecules are produced?

$$10 \text{ molec } CH_4 \times \frac{2H_2O}{1CH_4} = 20 \text{ molec } H_2O$$

Question #2: In a reaction, 30 molecules of CO_2 is produced. How many molecules of oxygen reacted?

$$30 \text{ molec } CO_2 \times \frac{2O_2}{1CO_2} = 60 \text{ molec } O_2$$

Question #3: In reaction 3.2 moles of water was produced, how many moles of methane reacted?

$$3.2 \text{ moles } H_2O \times 1CH_4 / 2H_2O = 1.6 \text{ mol } CH_4$$

2. Using coefficients of balanced chemical equations to set up RATIOS for calculations:

$$1CH_4 + 2O_2 ------> 1CO_2 + 2H_2O + 891 \text{ kJ}$$

We use ratios to set up equations. For example, if we knew the number of moles of CH_4 that undergoes a chemical reaction and we needed to find out information regarding the water, we would use the following ratio:

$$\frac{1 \text{ mole } CH_4}{2 \text{ moles of } H_2O} \quad \text{or} \quad \frac{2H_2O}{1CH_4}$$

In fact, we use the balanced equation to set up ratios between any chemical present in the chemical reaction (as well as energy, really!!).

For example, if we wanted to perform calculations between **CH_4** and **O_2** we would use the ratios:

$$\frac{2O_2}{1CH_4} \quad \text{or} \quad \frac{1CH_4}{2O_2}$$

or if we wanted to find information between **oxygen** and **water**, we would use the following ratios:

$$\frac{2O_2}{2H_2O} \quad \text{or} \quad \frac{2H_2O}{2O_2}$$

Examples of calculations involving stoichiometric ratios:

1. How many moles of hydrogen gas are required to react with 2.5 moles of oxygen to produce water ? (a synthesis reaction)

   1) write a balanced equation: $2H_2 + O_2 \rightarrow 2H_2O$

   2) set up equation using ratio in such a way so you cancel the units:

$$2.5 \text{ mol } O_2 \times \frac{2H_2}{1O_2} = 5.0 \text{ mol } H_2$$

2. How many moles of hydrochloric acid will be required to produce 0.40 moles of hydrogen gas by reacting with zinc? (a single replacement reaction)

$$Zn + 2HCl \rightarrow ZnCl_2 + H_2$$

$$0.40 \text{ mol } H_2 \times \frac{2HCl}{1H_2} = 0.80 \text{ mol } HCl$$

3. How many moles of hydrogen will be required to produce 1.70 moles of ammonia, NH_3? (another synthesis reaction) $3H_2 + N_2 \rightarrow 2NH_3$

$$1.70 \text{ mol } NH_3 \times \frac{3H_2}{2NH_3} = 2.55 \text{ mol } H_2$$

4. Consider the reaction: $3 I_2 + 6 F_2 -----> 2 IF_5 + I_4F_2$

a) How many moles of I_4F_2 are produced when 3.75 mole of I_2 reacts?

$$3.75 \text{ mol } I_2 \times \frac{1I_4F_2}{3I_2} = 1.25 \text{ mol } I_4F_2$$

b) How many moles of Fluorine reacted if 3.07×10^{-3} moles of I_4F_2 are produced?

$$3.07 \times 10^{-3} \text{mol } I_4F_2 \times \frac{6F_2}{1I_4F_2} = 1.84 \times 10^{-2} \text{mol } F_2$$

c) How many moles of IF_5 are produced when 0.035moles of F_2 react?

$$0.035 \text{mol } F_2 \times \frac{2IF_5}{6F_2} = 0.012 \text{mol } IF_5$$

More Practice Problems: Remember to use Stoichiometric Ratios to solve the following problems:

5. Consider the reaction: $C_3H_8 + 5 O_2 ---> 3 CO_2 + 4 H_2O$

a) How many oxygen molecules is needed to react with 12 molecules of propane, C_3H_8?

$$12 \text{molec } C_3H_8 \times \frac{5O_2}{1C_3H_8} = 60 \text{molec } O$$

b) How many moles of water is produced when 2.5 moles of oxygen react with enough propane?

$$2.5 \text{mol } O_2 \times \frac{4H_2O}{5O_2} = 2.0 \text{mol } H_2O$$

c) How many moles of CO_2 is produced when 25 molecules of propane reacts with sufficient amount of oxygen?

$$25 \text{molec } C_3H_8 \times \frac{3CO_2}{1C_3H_8} = 75 \text{molec } CO_2$$

d) How many moles of oxygen is needed to react with sufficient amount of propane to produce 3.0×10^{-2} moles of water?

$$3.0 \times 10^{-2} \text{mol } H_2O \times \frac{5O_2}{4H_2O} = 3.8 \times 10^{-2} \text{mol } O_2$$

6. In the reaction: $3 Fe + 4 H_2O ---> Fe_3O_4 + 4 H_2$

a) How many moles of Fe_3O_4 is produced when 0.034 mole of Fe reacts with sufficient amount of water?

$$0.034 \text{mol Fe} \times \frac{1Fe_3O_4}{3Fe} = 0.011 \text{mol } Fe_3O_4$$

b) How many moles of water is needed to react with 13.5 moles of Fe?

$$13.5 \text{mol Fe} \times \frac{4H_2O}{3Fe} = 18.0 \text{mol } H_2O$$

c) How many molecules of Fe_3O_4 are produced when 250 atoms of Fe react?

$$250 \text{ Fe} \times \frac{Fe_3O_4}{3Fe} = 83 \text{ molec } Fe_3O_4$$

## 3. Stoichiometry Calculations involving moles, mass, gas volume and molecules:

- In any balanced equation, the moles of one chemical is related to the moles of another chemical by the stoichiometric ratio.
- We can use this concept to make important practical predictions regarding a chemical reaction. In the "moles" unit, we learned that the MOLE can be used to make calculations dealing with mass, volume of gas, and number of molecules. So, in any reaction, we can now

use the information such as the mass of one chemical, and calculate the mass of another chemical.

- The key to making calculations is to use the relationship between chemicals in a balanced chemical equation. A good way to visualize the connection between the moles of the two chemicals in a particular problem is to use the **"MOLE HILL"**.

balanced equation

$$3\ I_2 + 6\ F_2 \ -----> 2\ IF_5 + I_4F_2$$
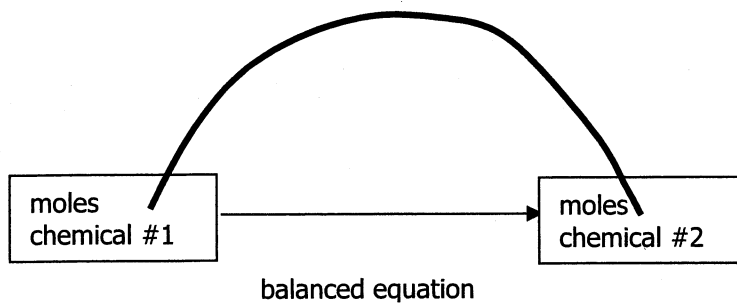
The **"MOLE HILL"** is the relationship between chemical #1 and chemical #2. Since the mole is related to mass, volume of gas and number of particles, we can use another diagram to illustrate all the connections which can be made when performing stoichiometric calculations:
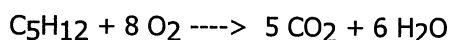

4

mass
volume
particles

mass
volume
particles
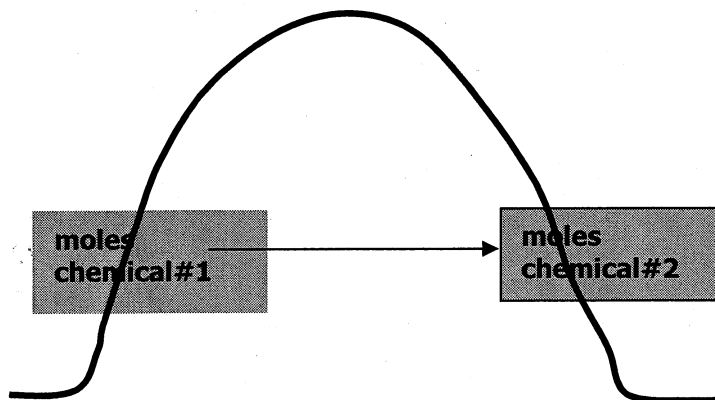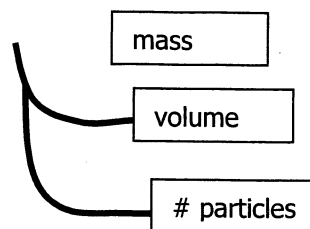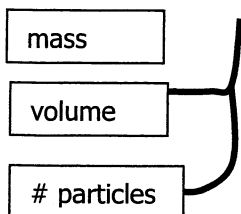
Given some information (mass, volume, # particles) of chemical 1, we need to climb the "MOLE HILL" (stoichimetric ratio) in order to find information of chemical #2.
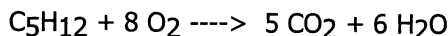
Examples:

1. What mass of carbon dioxide is produced when 2.3 moles of pentane (C_5H_{12}) are burned?

$$C_5H_{12} + 8\ O_2 \longrightarrow 5\ CO_2 + 6\ H_2O$$

$$2.3\ mol\ C_5H_{12} \times \frac{5\ CO_2}{1\ C_5H_{12}} \times \frac{44.0g}{1mol} = 510g$$

2. How many moles of Carbon dioxide is produced if 3.0 g of oxygen reacts with sufficient pentane?

$$C_5H_{12} + 8\ O_2 \longrightarrow 5\ CO_2 + 6\ H_2O$$

$$3.0g\ O_2 \times \frac{1mol}{32.0g} \times \frac{5\ CO_2}{8\ O_2} = 0.059\ mol\ CO_2$$

3. What mass of C_3H_8 is required to produce 5.0×10^{-2} mole of H_2O?

$$\begin{array}{c} 3\times12.0 \\ 8\times1.0 \\ \hline 44.0g/mol \end{array}$$

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$
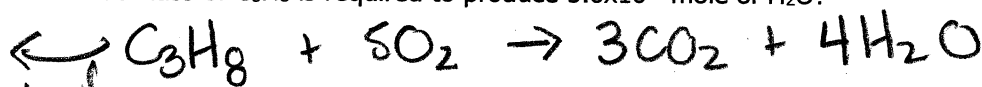
$$5.0\times10^{-2}\ mol\ H_2O \times \frac{1mol}{18.0g} \times \frac{1\ C_3H_8}{4\ H_2O} \times \frac{44.0g}{1mol} = 0.031g\ C_3H_8$$

4. What volume of fluorine gas will be needed to produce 5.60 grams of hydrogen fluoride by reacting with hydrogen? Assume STP conditions.

$$F_2 + H_2 \rightarrow 2HF$$

$$5.60g \times \frac{1mol}{20.0g} \times \frac{1\ F_2}{2\ HF} \times \frac{22.4L}{1mol} = 3.14\ L\ F_2$$

5

$$C + O_2 \rightarrow CO_2$$

5. How many grams of carbon will react with 0.25g of oxygen to produce carbon dioxide?

$$0.25g \times \frac{1 mol}{32.0g} \times \frac{1C}{1O_2} \times \frac{12.0g}{1 mol} = 0.094 gC$$

6. What mass of oxygen can be produced when 13.6 grams of sulfur trioxide are decomposed?

$$2SO_3 \rightarrow 2S + 3O_2$$

$$13.6g \times \frac{1 mol}{80.1g} \times \frac{3O_2}{2SO_3} \times \frac{32.0g}{1 mol} = 8.15g\, O_2$$

7. What volume of hydrogen gas is produced (STP) when 1.0g of magnesium reacts with hydrochloric acid?

$$Mg + 2HCl \rightarrow MgCl_2 + H_2$$

$$1.0g \times \frac{1 mol}{24.3g} \times \frac{1H_2}{1Mg} \times \frac{22.4L}{1 mol} = 0.92 L\, H_2$$

8. If 2.0L of hydrogen reacts with oxygen, what is the volume of water vapour produced at STP?

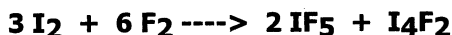$$2H_2 + O_2 \rightarrow 2H_2O$$

$$2.0L \times \frac{1 mol}{22.4} \times 2H_2O/2H_2 \times \frac{22.4L}{1 mol} = 2.0L\, H_2O$$

Chemistry 11
Stoichiometric Calculations with Mass

1. Consider the following equation :

$$3 I_2 + 6 F_2 \longrightarrow 2 IF_5 + I_4F_2$$

a) How many moles of I_4F_2 are produced by the complete reaction of 5.41 moles of fluorine?

$$5.41\ mol\ F_2 \times \frac{1 I_4F_2}{6F_2} = 0.902\ mol\ I_4F_2$$

b) How many moles of fluorine are needed to produce 4.52 moles of IF_5?

$$4.52\ mol\ IF_5 \times \frac{6F_2}{2IF_5} = 13.6\ mol\ F_2$$

c) What mass of iodine is needed to react with 7.63 grams of fluorine?

$$7.63g \times \frac{1 mol}{38.0g} \times \frac{2IF_5}{3I_2} \times \frac{253.8g}{1 mol} = 25.5g\, I_2$$

6

d) What mass of IF_5 is produced by the reaction of 154 grams of iodine?

$$154g \times \frac{1mol}{253.8g} \times \frac{2IF_5}{3I_2} \times \frac{221.9g}{1mol} = 89.8g\ IF_5$$

2. $C_5H_{12} + 8\ O_2 \longrightarrow 5\ CO_2 + 6\ H_2O$

a) What mass of BOTH products (separately) are formed when 105 g of pentane (C_5H_{12}) are burned ?

$$105g \times \frac{1mol}{72.0g} \times \frac{5CO_2}{1C_5H_{12}} \times \frac{44.0g}{1mol} = 321g\ CO_2$$

$$105g \times \frac{1mol}{72.0g} \times \frac{6H_2O}{1C_5H_{12}} \times \frac{18.0g}{1mol} = 158g\ H_2O$$

b) What mass of oxygen is needed to produce 66.0 g of water, according to the above reaction?

$$66.0g \times \frac{1mol}{18.0g} \times \frac{8\ O_2}{6H_2O} \times \frac{32.0g}{1mol} = 156g\ O_2$$

c) What volume of CO_2 gas is produced (assume STP conditions) if 2.00 g of oxygen reacts with sufficient pentane.

$$2.00g\ O_2 \times \frac{1mol}{32.0g} \times \frac{5CO_2}{8O_2} \times \frac{22.4\iota}{1mol} = 0.875\ L\ CO_2$$

3. $5\ C + 2\ SO_2 \longrightarrow CS_2 + 4\ CO$

a) How many moles of carbon disulfide are produced by reacting 241 g of carbon?

$$241g\ C \times \frac{1mol}{12.0g} \times \frac{1CS_2}{5C} = 4.02\ mol\ CS_2$$

b) If we wish to produce 7.60 g of carbon disulfide, what mass of carbon should we use

$$7.60g \times \frac{1mol}{76.2g} \times \frac{5C}{1CS_2} \times \frac{12.0g}{1mol} = 5.98g\ C$$
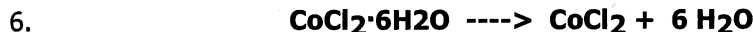
4. $2\ CuO \longrightarrow 2\ Cu + O_2$

What mass of copper would result from decomposing 101 grams of cupric oxide?

$$101g\ CuO \times \frac{1mol}{79.5g} \times \frac{2Cu}{2CuO} \times \frac{63.5g}{1mol} = 80.7g\ Cu$$

5. $4\ NH_3 + 7\ O_2 \longrightarrow 4\ NO_2 + 6\ H_2O$

What mass of water is produced by the reaction of 3.40 grams of ammonia according to the above reaction?

$$3.40g\ NH_3 \times \frac{1mol}{17.0g} \times \frac{6H_2O}{4NH_3} \times \frac{18.0g}{1mol} = 6.56\ g\ H_2O$$

6. $CoCl_2 \cdot 6H_2O$ ----> $CoCl_2$ + 6 H_2O

If you used 4.67 g of the hydrate, what mass of water would be driven off?

$$4.67g \times \frac{1mol}{237.9} \times \frac{6H_2O}{1 CoCl_2 \cdot 6H_2O} \times \frac{18.0g}{1mol} = 2.12g \ H_2O$$

7. Given the reaction: 3 H_2 + N_2 ---> 2 NH_3
a) Calculate the volume of N_2 gas at STP, needed to react with 2.33 g of H_2?

$$2.33g \ H_2 \times \frac{1mol}{2.0g} \times \frac{1N_2}{3H_2} \times \frac{22.4L}{1mol} = 8.70L \ N_2$$

b) Calculate the volume gas of NH_3 produced if 3.0 L of hydrogen gas react with enough nitrogen gas. $3H_2 + N_2 \Rightarrow 2NH_3$

$$3.0L \ H_2 \times \frac{2NH_3}{3H_2} = 2.0L \ NH_3$$

CHEMISTRY 11
STOICHIOMETRY PROBLEMS WITH VOLUMES & ENERGY

Examples:

1.   3 H_2 + N_2 ---> 2 NH_3 + 92kJ

a) How many litres of hydrogen are required to produce 5.0 litres of NH_3 at the same temperature and pressure? Assume STP conditions.
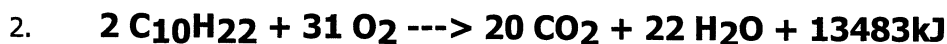
$$5.0L \ NH_3 \times \frac{3H_2}{2NH_3} = 7.5L \ H_2$$

b) What amount of energy is released when 5.00 grams of NH_3 are produced?

$$5.00g \ NH_3 \times \frac{1mol}{17.0g} \times \frac{92kJ}{2NH_3} = 13.5kJ$$

c) Given the reaction above, what mass of nitrogen is needed to produce 889.0 kJ of energy?

$$889.0kJ \times \frac{N_2}{92kJ} \times \frac{28.0g}{1mol} = 270g \ N_2$$
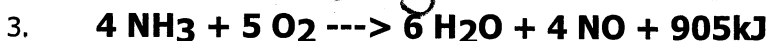
2. $2 C_{10}H_{22} + 31 O_2 \longrightarrow 20 CO_2 + 22 H_2O + 13483kJ$

a) What volume of CO_2 is produced when 17.4 litres of oxygen is used?

$$17.4 L\, O_2 \times \frac{20\, CO_2}{31\, O_2} = 11.2 L\, CO_2$$

b) What amount of energy is released when 1.00 gram of $C_{10}H_{22}$ is burned?

$$1.00g \times \frac{1\, mol}{142.0g} \times \frac{13483\, kJ}{2\, C_{10}H_{22}} = 47.5 kJ$$

3. $4 NH_3 + 5 O_2 \longrightarrow 6 H_2O + 4 NO + 905kJ$

a) What mass of NO is produced when 2.0 moles of NH_3 react?

$$2.0\, mol\, NH_3 \times \frac{4\, NO}{4\, NH_3} \times \frac{30.0g}{1\, mol} = 60.0g\, NO$$

b) What volume of NH_3 is required to react with 3.00 litres of oxygen?

$$3.00 L\, O_2 \times \frac{4\, NH_3}{5\, O_2} = 2.40 L\, NH_3$$

$$4 NH_3 + 5 O_2 \longrightarrow 6 H_2O + 4 NO + 905kJ$$

c) What volume of gaseous water is produced along with 2.83 litres of NO?

$$2.83 L\, NO \times \frac{6\, H_2O}{4\, NO} = 4.25 L\, H_2O$$

d) How much energy is produced when 2.70 grams of NH_3 are burned?

$$2.70g\, NH_3 \times \frac{1\, mol}{17.0g} \times \frac{905\, kJ}{4\, NH_3} = 35.9 kJ$$

e) If 200.0kJ of heat are produced, what mass of both products are also formed?

$$200 kJ \times \frac{6\, H_2O}{905\, kJ} \times \frac{18.0g}{1\, mol} = 23.9g\, H_2O$$

$$200 kJ \times \frac{4\, NO}{905\, kJ} \times \frac{30.0g}{1\, mol} = 26.5g\, NO$$

4. Nitromethane, a fuel occasionally used in some drag racers, burns according to the following reaction:

$$4 CH_3NO_{2(l)} + 3 O_{2(g)} \longrightarrow 4 CO_{2(g)} + 6 H_2O_{(l)} + 2 N_{2(g)}$$
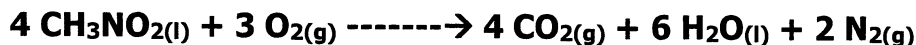
a) What is the volume of CO_2 is produced at STP if 0.335g of nitromethane burns?

$$0.335g \times \frac{1\, mol}{61.0g} \times \frac{4\, CO_2}{4\, CH_3NO_2} \times \frac{22.4 L}{1\, mol} = 0.123 L\, CO_2$$

b) What volume of O_2 is required to produce 0.250g of CO_2?

$$0.250g\ CO_2 \times \frac{1mol}{44.0g} \times \frac{3O_2}{4CO_2} \times \frac{22.4L}{1mol} = 0.0955L$$

c) How many molecules of N_2 is produced when 3.0g of nitromethane burns?

$$3.0g \times \frac{1mol}{61.0g} \times \frac{2N_2}{4CH_3NO} \times \frac{6.02\times10^{23}}{1mol} = 1.5\times10^{22}N_2$$

d) If 3.0×10^{24} molecules of nitromethane reacts, what mass of CO_2 is produced?

$$3.0\times10^{24} \times \frac{1mol}{6.02\times10^{23}} \times \frac{4CO_2}{4CH_3NO} \times \frac{44.0g}{1mol} = 220g\ CO_2$$

e) If 2.0 g of CH_3NO_2 reacts with sufficient oxygen, calculate the number molecules of CO_2 that is produced.

$$2.0g \times \frac{1mol}{61.0g} \times \frac{4CO_2}{4CH_3NO} \times \frac{6.02\times10^{23}}{1mol} = 2.0\times10^{22}\ CO_2$$

Chemistry 11 Stoichiometry Take Home Test

Name:_____ Date: _____ block: _____

Write a balanced equation and then solve each problem showing work and place the answer with correct significant figures and units on the space provided:

1. How many moles of water can be formed when 0.23 moles of hydrogen gas is burned? (3 marks)
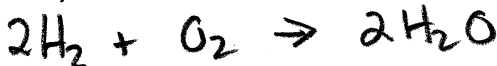
$$2H_2 + O_2 \rightarrow 2H_2O$$

$$0.23\ mol\ H_2 \times \frac{2H_2O}{2H_2}$$

ans: _____0.23mol_____

2. Sodium metal reacts vigorously with water to form hydrogen gas and NaOH. In a demonstration, the teacher placed 1.2 grams of sodium into water, calculate the number of moles of hydrogen gas that would be generated in this reaction. (3 marks)

$$2Na + H_2O \rightarrow H_2 + Na_2O$$

$$1.2g \times \frac{1mol}{23.0g} \times \frac{H_2}{2Na}$$

ans: _____0.026 mol_____

3. Given the following reaction: $4\ NH_3 + 5\ O_2 \longrightarrow 6\ H_2O + 4\ NO + 905kJ$

a) What mass of NO is produced when 0.230 moles of NH_3 react ? (3 marks)

$$0.230\text{mol } NH_3 \times \frac{4NO}{4NH_3} \times \frac{30.0g}{1mol}$$

ans: ___6.90g NO___

b) What volume of NH_3 is required to react with 1.40 litres of oxygen? Assume STP conditions. (3 marks)

$$1.40L\ O_2 \times \frac{1mol}{22.4L} \times \frac{4NH_3}{5O_2} \times \frac{22.4L}{1mol}$$

ans: ___1.12L NH_3___

c) How much energy is produced when 0.700 grams of O_2 are burned? (3 marks)

$$0.700g\ O_2 \times \frac{1mol}{32.0g} \times \frac{905kJ}{5O_2}$$

ans: ___3.96kJ___

e) If 2400 kJ of heat are produced, what mass of NH_3 reacted? (3 marks)

$$2400kJ \times \frac{4NH_3}{905kJ} \times \frac{17.0g}{1mol} =$$

ans: ___180g NH_3___

4. How many grams of aluminum oxide are formed when 8.0 g of oxygen gas react completely with aluminum? (4 marks)

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

$$8.0g \times \frac{1mol}{32.0} \times \frac{2Al_2O_3}{3O_2} \times \frac{102g}{1mol} = 17g\ Al_2O_3$$
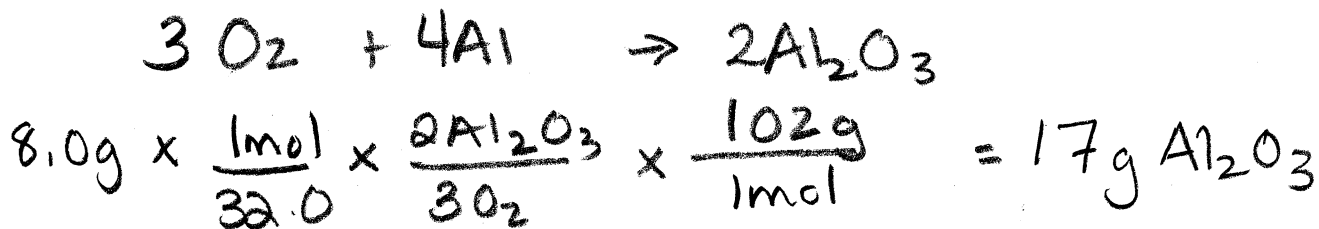
ans: _____

5. Calculate the energy produced when 3.0g $C_{10}H_{22}$ reacts with oxygen? (4 marks)

$$2\ C_{10}H_{22} + 31\ O_2 \longrightarrow 20\ CO_2 + 22\ H_2O + 13483\text{kJ}$$

$$3.00g \times \frac{1mol}{142.0g} \times \frac{13483\,KJ}{2\,C_{10}H_{22}}$$

ans: ___142 KJ___

4. Stoichiometry Calculations Involving Molar Concentration

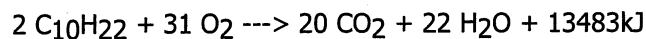**Molar Concentration:** $C = \dfrac{n}{V}$, $n = CV$

Note: The volume is the volume of solution and not the volume of gas at STP.

Examples:

1. a) The main component found in Tums™ is $CaCO_3$. Stomach acid contains a dilute solution of hydrochloric acid, having a concentration of 0.0010M. If a tablet of Tums™ contains 0.70 g of $CaCO_3$, calculate the volume of stomach acid that will be neutralized by the tablet.

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + \boxed{H_2CO_3}$$
$$\hookrightarrow H_2O + CO_2$$
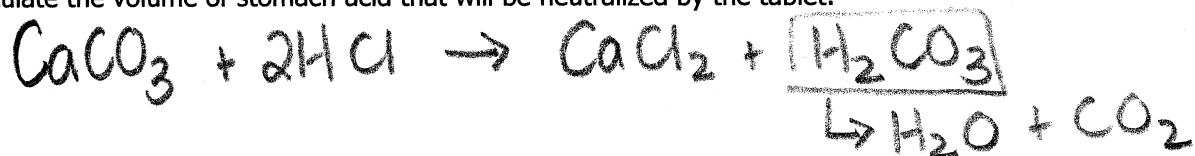
$$0.70g\ CaCO_3 \times \frac{1mol}{100.1g} \times \frac{2HCl}{1\,CaCO_3} = 0.014\ mol\ HCl$$

$$V = \frac{n}{C} = \frac{0.014\,mol}{0.0010M} = 14L$$

b) What volume of $CO_{2(g)}$ at STP is produced if 0.10L of 0.0010M HCl reacts with excess amount of $CaCO_3$?

$$mol = M \times V = 0.0010M \times 0.10L = 1.0 \times 10^{-4}\,mol$$

$$1.0 \times 10^{-4}\,mol\ HCl \times \frac{1\,CO_2}{2HCl} \times \frac{22.4L}{1mol} = 0.0011\,L$$

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

2. What volume of 0.24M NaOH is needed to neutralize 10.00mL of 0.320M H_2SO_4?

$$0.01000L \times 0.320M = 3.2 \times 10^{-3} mol\ H_2SO_4$$

$$3.2 \times 10^{-3} mol\ H_2SO_4 \times \frac{2NaOH}{1H_2SO_4} = 6.4 \times 10^{-3} mol\ NaOH$$

$$L = \frac{n}{M} = \frac{6.4 \times 10^{-3} mol}{0.24M} = 0.0267\ L\ or\ 26.7 mL$$

Definition: Titration is an analytical technique used to determine the concentration of an unknown solution. To carry out this analytical method, the chemist would measure accurately the volume of a solution of unknown concentration and react with a solution of known concentration. The volume of the known solution is determined by finding what is called the **EQUIVALENCE POINT** (stoichiometric point). This equivalence point occurs when all the ratio of moles of each specie involved in the reaction equals the exact ration as determined from a balanced equation.

3. In a titration, 10.00 mL of a vinegar solution (acetic acid) is reacted with a 0.10M NaOH solution. The volume of NaOH when the equivalence point has been reached is 23.30 mL. What is the concentration of acetic acid (CH_3COOH) in vinegar?

$$NaOH + CH_3COOH \rightarrow NaCH_3COO + H_2O$$
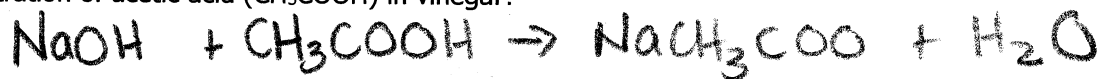
$$\underbrace{0.10M \times 0.02330L}_{mol\ NaOH} \times \frac{1CH_3COOH}{1NaOH} \times \frac{1}{0.01000L} = 0.233M$$

4. What volume of 0.200M KOH is needed to react with 250.0mL of 0.150M H_3PO_4 in order to produce a solution of KH_2PO_4.

$$KOH + H_3PO_4 \rightarrow KH_2PO_4 + H_2O$$

$$0.2500L \times 0.150M \times \frac{1\ KOH}{1H_3PO_4} \times \frac{1}{0.200M} = 0.1875$$

(188mL)

5. If 50.0 mL of 0.20M $CaCl_2$ reacts with sufficient amount of Na_2CO_3, calculate the mass of $CaCO_3$ produced in this reaction.

$$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaCl$$
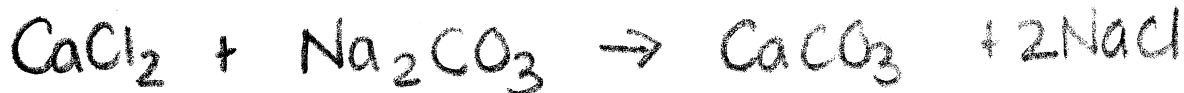
$$\underbrace{0.0500L \times 0.20M}_{mol\ CaCl_2} \times \frac{1CaCO_3}{1CaCl_2} \times \frac{100.1g}{1mol} = 1.0g$$

6. Aluminum reacts with sodium hydroxide solution to produce hydrogen gas as illustrated by the reaction:

$$2Al_{(s)} + 2NaOH_{(aq)} + 2 H_2O_{(l)} \text{----------} > 2 NaAlO_{2(aq)} + 3 H_{2(g)}$$

What volume of a 3.00M NaOH solution is needed to produce 50.0L of hydrogen gas?

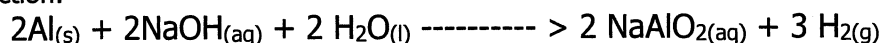$$50.0L \times \frac{1mol}{22.4L} \times \frac{2NaOH}{3H_2} \times \frac{1}{3.00M} = 0.500L$$

Chemistry 11
Stoichiometry Calculations with Molar Concentration

$$2HCl + MgCOH)_2 \rightarrow 2H_2O + mgCl_2$$

1. What volume of 0.222M HCl is needed to neutralize 50.0mL of 0.32M Mg(OH)₂?

$$\underbrace{0.0500L \times 0.32M}_{mol\ Mg(OH)_2} \times \frac{2HCl}{1mg(OH)_2} \times \frac{1}{0.222M} = 0.14\ L$$

2. A 10.00 mL sample of Ca(OH)₂ is titrated with 33.04mL of 0.0122M HCl.
a) What is the molarity of Ca(OH)₂?

$$0.03304L \times 0.0122M \times \frac{1Ca(OH)_2}{2HCl} \times \frac{1}{0.01000L}$$

$$= 0.0202M$$

b) What mass of Ca(OH)₂ is dissolved in the 10.00 mL sample?

$$0.0202M \times 0.01000L \times \frac{74.1g}{1mol} = 0.015g$$

3. Given the following reaction between mercury ion and chloride ion:

$$Hg^+_{(aq)} + 2Cl^-_{(aq)} \text{----------} > HgCl_{(s)}$$
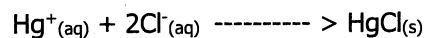
A 25.0mL water sample containing mercury ion, reacts with 10.0 mL of 0.0133M Cl⁻. What is the concentration of mercury ion in the water sample?

$$\underbrace{0.0100 \times 0.0133M}_{mol\ Cl^-} \times \frac{1Hg^+}{2Cl^-} \times \frac{1}{0.0250L}$$

$$= 0.00266M$$

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$$Pb(NO_3)_2 + 2KI \rightarrow PbI_2 + 2KNO_3$$

4. 25.0 mL of 0.10M $Pb(NO_3)_2$ reacts with sufficient KI solution. Calculate the mass of $PbI_{2(s)}$ produced in this reaction.

$$0.0250\,L \times 0.10\,M \times \frac{1\,PbI_2}{1\,Pb(NO_3)_2} \times \frac{461g}{1mol} = 1.15g$$

mol $Pb(NO_3)_2$

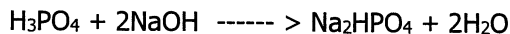5. A 10.00 mL sample of phosphoric acid solution is titrated with a 0.200M NaOH solution. The endpoint is reached when 17.03mL of NaOH is added. Calculate the concentration of the H_3PO_4 solution.

$$H_3PO_4 + 2NaOH \ ------> Na_2HPO_4 + 2H_2O$$

$$0.200\,M \times 0.01703\,L \times \frac{1\,H_3PO_4}{2\,NaOH} \times \frac{1}{0.01000\,L} =$$

mol NaOH

$$0.170\,M$$

6. In a chemical reaction, 0.225g of solid $BaSO_4$ is produced. If 100.0mL of a solution of $Ba(NO_3)_2$ of unknown concentration is mixed with excess amount of Na_2SO_4 solution, calculate the concentration of $Ba(NO_3)_2$.

$$Ba(NO_3)_2 + Na_2SO_4 \rightarrow BaSO_4 + 2NaNO_3$$

$$0.225g \times \frac{1mol}{233.4g} \times \frac{1\,Ba(NO_3)_2}{1\,BaSO_4} \times \frac{1}{0.1000\,L} = 9.6\times10^{-3}\,M$$

7. In order to analyze a sample of rock for iron, the rock was reacted with acid. The iron in the rock is converted into $Fe^{2+}_{(aq)}$. The concentration of iron cation is determined by reacting with dichromate ion as illustrated by the reaction:

$$Cr_2O_7^{2-}{}_{(aq)} + 6\,Fe^{2+}{}_{(aq)} + 14H^+{}_{(aq)} \ ------> 2\,Cr^{3+}{}_{(aq)} + 6\,Fe^{3+}{}_{(aq)} + 7\,H_2O_{(l)}$$
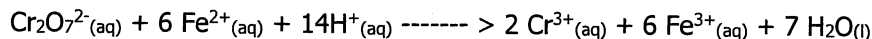
If 17.0 mL of 0.133M dichromate ion is required to titrate (exact stoichiometric ratio) with 25.00 mL of Fe^{2+} solution,
a) What is the molarity of Fe^{2+}?

$$0.0170\,L \times 0.133\,M \times \frac{6\,Fe^{2+}}{1\,Cr_2O_7^{2-}} \times \frac{1}{0.0250\,L}$$

$$= 0.543\,M$$

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b) What mass of iron is present in the 25.00mL sample?

$$0.02500 \text{ L} \times 0.543 \text{ M} \times \frac{55.8g}{1 \text{ mol}} = 0.757g$$

5. Stoichiometric calculations with one reactant in excess

Most of the time when we have a reaction, we add too much of one reactant or another. Because of this, onlyone of the reactants is completely used up and the other will have some remaining. In order to solve stoichiometric problems, the reactant that we run out of first (called the limiting reagent) is the one we MUST use in the calculations. Reason ? We do not know how much of the other reactant is actually used and how much is in excess (INXS).

Example #1 : Ba + S ---> BaS
If we have 10.0 grams of each reactant a) which will be used up first ?
b) what mass BaS will be produced?

	Ba	S	BaS
I	$\frac{10.0g}{137.3g}$ 0.0728 -x	$\frac{10.0g}{32.1}$ 0.312 mol -x	0 x
C	-0.0728		
E	∅	0.239 mol	$0.0728 \text{ mol} \times \frac{169.4g}{1 \text{ mol}}$ = 12.3g

example #2 -
A double replacement reaction takes when 60.0 g of zinc chloride is mixed with 60.0 g of hydrogen phosphate. When the reaction is complete, determine the mass of each remaining particle.
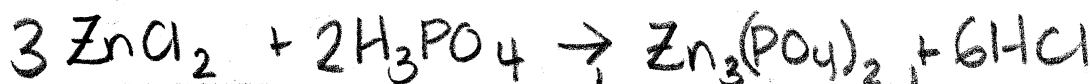
$$3 ZnCl_2 + 2H_3PO_4 \rightarrow Zn_3(PO_4)_2 + 6HCl$$

I	60g/136.4g 0.440	60g/98.0g 0.612	0	0
	-3x x=0.147	-2x x=0.306	+ x	+ 6x
C	-0.440	-0.294		
E	∅	0.318 mol × 98.0g 31.2g	0.147 mol × 386.2g 56.8g	0.882 mol × 36.5g 32.1g

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

3. a) If 10.0 g of hydrogen reacts with 10.0 g of oxygen, determine the reactant that is in excess amount.

	H_2	O_2	H_2O
I	10.0g / 2.0 = 5.00	10.0/32 = 0.3125	0
C	$-2x$ -0.625	$-x$ -0.3125	$+2x$ 0.625
E	4.375	0	0.625

b) Calculate the mass of water produced in this reaction.

$$0.625 \text{ mol} \times \frac{18.0 g}{1 \text{ mol}} = 11.3 g$$

c) Calculate the mass of the reactant that is in excess that is left over?

$$4.375 \text{ mol} \times \frac{2.0 g}{1 \text{ mol}} = 8.75 g$$

4. If 50.0mL of 0.100M HCl is allowed to react with 30.0mL of 0.200M NaOH, which reactant is in excess?

limiting

	HCl	NaOH	NaCl	H_2O
I	0.0050	0.0060	0	0
C	$-x$ -0.0050	$-x$ -0.0050	$+x$ $+0.0050$	$+x$ $+0.0050$
E	0	0.0010	0.0050	0.0050

5. What mass of Br_2 is produced when 25.0g of $K_2Cr_2O_7$, 55.0 g of KBr and 60.0 g of H_2SO_4 are reacted according to the equation:

$$K_2Cr_2O_7 + 6KBr + 7H_2SO_4 \longrightarrow 4K_2SO_4 + Cr_2(SO_4)_3 + 3Br_2 + 7H_2O$$
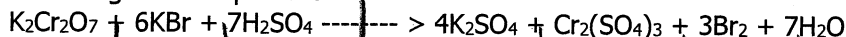
	$K_2Cr_2O_7$	KBr	H_2SO_4	K_2SO_4	$Cr_2(SO_4)_3$	Br_2	H_2O
I	25.0g/294.2 0.0850	55.0/ 0.462	60.0/98 0.612	0	0	0	
C	-0.077	$-6x$	-0.539	$+4x$	$+x$	$+3x$	$+7x$
E	0.0080	0	0.073	0.308	0.077	0.231	0.539

5. Percent yield and percentage purity

$$0.231 \times \frac{159.8 g}{\text{mol}}$$

$$\boxed{36.9 g}$$

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- Sometimes 100% of the expected amount of product cannot be obtained from a reaction.
- Percentage Yield – amount of product actually produced as a percentage of the expected amount.

$$\text{Percent yield} = \frac{\text{Mass of product obtained}}{\text{Mass of product expected}} \times 100\%$$

- Reasons for reduced yield:

    1) reactants may not react
    2) reactants may be less than 100% pure
    3) products are lost

- Another important term is percent purity

$$\text{Percent purity} = \frac{\text{Mass of pure reactant}}{\text{Mass of impure reactant}} \times 100\%$$

Examples:

1) When 15.0 g of CH_4 is reacted with an excess of Cl_2 according to the reaction

$$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$$

a total mass of 29.7 g of CH_3Cl is formed. What is the percent yield of the reaction?

First find the mass of CH3Cl expected (assume 100% yield)

$$15.0g \; CH_4 \times \frac{1 \, mol}{16.0 \, g} \times \frac{CH_3Cl}{1CH_4} \times \frac{50.5g}{1mol} = 47.3g$$

% yield =

$$\frac{29.7g}{47.3g} = 62.8\%$$

2) What mass of K_2CO_3 is produced when 1.50 g of KO_2 is reacted with an excess of CO_2 according to the reaction
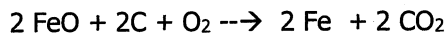
$$4KO_2 + 2CO_2 \rightarrow 2 K_2CO_3 + 3 O_2$$

If the reaction has 76.0 % yield?

First calculate the mass of K_2CO_3 produced (assuming 100% yield)

$$1.50g \times \frac{1mol}{71.1g} \times \frac{2K_2CO_3}{4KO_2} \times \frac{138.2g}{1mol} = 1.46 \, g \times 0.76 =$$

$$\boxed{1.11g}$$

Now introduce the fact that the percentage yield is 76% which reduces the mass of K_2CO_3 expected.

3) If 100.0 g of FeO produce 12.9 g of pure Fe according to the reaction

$$2 FeO + 2C + O_2 \rightarrow 2 Fe + 2 CO_2$$

What is the percentage purity of the FeO used?

$$100.0g \times \frac{1mol}{71.8g} \times \frac{2Fe}{2FeO} \times \frac{55.8g}{1mol} = 77.7g \qquad \frac{12.9}{77.7} \times 100 \; \boxed{16.6\%}$$

First calculate the mass of pure FeO which forms 12.9 g of Fe

Percentage purity = 16.6%

4. The roasting of Siderite ore, $FeCO_3$, produces iron III oxide:

$$4\ FeCO_3 + O_2 \rightarrow 2\ Fe_2O_3 + 4\ CO_2$$
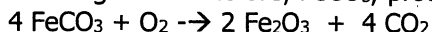
a) A 15.0 g $FeCO_3$ sample is 42% pure. What mass of Fe_2O_3 can the sample produce?

$$15.0g \times 0.42 \times \frac{1\ mol}{115.8g} \times \frac{2Fe_2O_3}{4FeCO_3} \times \frac{159.6g}{1mol} = 4.34\ g$$

b) A second sample of FeCO3, with a mass of 55.0 g, is roasted so as to produce 37.0 g of Fe_2O_3. What is the percentage purity of $FeCO_3$?

$$55.0g \times \frac{1mol}{115.8g} \times \frac{2Fe_2O_3}{4FeCO_3} \times \frac{159.6g}{1mol} = 37.9\ g \qquad \frac{37.0}{37.9} \times 100$$

$$\boxed{97.6\%}$$

c) A 35 g sample of pure $FeCO_3$ produces 22.5 g of Fe_2O_3. What is the percentage yield of the reaction?

$$35g \times \frac{1mol}{115.8} \times \frac{2\ Fe_2O_3}{4\ FeCO_3} \times \frac{159.6g}{1mol} = 24.1g \qquad \frac{22.5}{24.11} \times 100 = 93.3\%$$

d) What mass of siderite ore with a purity of 62.8 % is needed to make 1.00 kg of Fe_2O_3?

$$\frac{1000g}{x} = \frac{62.8}{100} \qquad x = 1592g \times \frac{1mol}{115.8g} \times \frac{2Fe_2O_3}{4FeCO_3} \times \frac{159.6g}{1mol} = 2310g$$

Answers: a) 4.34 g   (b) 97.6%   (c) 93.3%   (d) 2.31 x 10 ^{3} g

Chemistry 11
Stoichiometry Limiting Reactant and percent yield

1. In an experiment, 50.0 mL of 0.60M $CaCl_2$ solution is mixed with 75.0 mL of 0.40M Na_2CO_3 solution. The solid product produced is filtered and allowed to dry. The following data is recorded:

Mass of filter paper: 1.07 g
Mass of filter paper + CaCO$_3$: 2.27 g

a) What is the balanced equation?

$$CaCl_2 + Na_2CO_3 \rightarrow 2NaCl + CaCO_3$$

b) What reactant is the limiting reactant?

Both

	CaCl$_2$	Na$_2$CO$_3$	NaCl	CaCO$_3$
I	0.050 × 0.6M	0.075 × 0.4		
	0.030	0.030		
C				
E	0	0		0.030

c) What is the theoretical yield?

$$0.030 \times \frac{100.1g}{1mol} = 3.00g$$

d) What is the % yield of the experiment?

$$\begin{array}{r} 2.27 \\ -1.07 \\ \hline 1.20 \end{array}$$

$$\frac{1.20}{3.00} \times 100 = 40.0\%$$

2. In a flask, 15.5 grams of aluminum metal are placed into a flask. In this flask, it is also placed 46.7 grams of chlorine gas. If the product formed is aluminum chloride,

a) Write a balanced equation:

$$2Al + 3Cl_2 \rightarrow 2AlCl_3$$

b) determine the limiting reactant.

Cl$_2$

Al	Cl$_2$	AlCl$_3$
15.5g/27	46.7g/71	0
0.574	0.658	
− 2x	−3x	+2x
−0.438		
0.136	0	0.438

b) calculate the mass of aluminum chloride produced.

$$0.438 mol \times \frac{133.5g}{1mol} = 58.5g$$

c) What is the compound that is in excess? By how much (mass) is it in excess?

$$Al : 0.136 \times \frac{27g}{1mol} = 3.67g$$

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e) If this reaction produced only 15.0 g of Aluminum chloride, calculate the percent yield.

$$\frac{15.0g}{58.5g} \times 100 = 25.6\%$$

2. Aluminum reacts with oxygen gas to produce Aluminum oxide. If 50.0 g of each reactant is placed in a reaction vessel, and allowed to react.
   a) What is the balanced equations?

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

   b) Which reactant is the limiting reactant?

(Al)

	Al	O_2	Al_2O_3
I	50/27	50/32	0
	1.85	1.56	
C	-4x	-3x -1.39	+2x
E	0	0.17	0.925

   c) What is the theoretical yield? That is, What is the mass of the product that would be produced according to theory?

$$0.925 mol \times \frac{102.0g}{1 mol} = 94.4g$$

   d) Which reactant is in excess? By how much (mass) is it in excess?

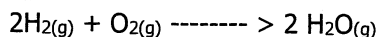$$O_2 : \quad 0.17 mol \times \frac{32.0g}{1 mol} = 5.4 g$$

   e) If the reaction produced only 22 g of the product (this is the experimental yield), what is the percent yield for this reaction? $22/94.4 \times 100 = 23.3\%$

STOICHIOMETRY QUESTIONS INVOLVING ONE LIMITING REACTANT.

1. Consider the following reation:
$$2H_{2(g)} + O_{2(g)} \text{-------} > 2 H_2O_{(g)}$$
   Identify the limiting reactant in each of the following mixtures:

   a) 50 molecules of hydrogen and 25 molecules of oxygen.

   b) 100 molecules of hydrogen and 40 molecules of oxygen.

   c) 0.50 mol of hydrogen and 0.75 mol of oxygen.

d) 0.80 mol hydrogen and 0.75 mol of oxygen.

e) 1.0 g of hydrogen and 0.25 mol of oxygen.

f) 5.00 g of hydrogen and 56 g of oxygen.

2. What mass of carbon dioxide is produced in the reaction that will occur when 16.0 g of EACH reactant are mixed and then reacted according to the following equation?   *(11.0 g)*
$$CH_4 + 2 O_2 ----> CO_2 + H_2O$$
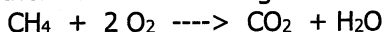
3. In a chemical reaction, 18.1 g of potassium are reacted with 14.0 g of oxygen to produce potassium oxide. a) Determine the limiting reactant and the mass of the product.   *(21.8g)* b) What is the reactant that is in excess quantity. By how much (mass) is it in excess? *(10.3g)*

4. Nitrogen can be prepared by passing gaseous ammonia over solid copper (II) oxide at high temperature. The product of the reaction is copper and water vapour. If a sample of 18.1 g of NH_3 is reacted with 90.4 g of CuO, which is the limiting reactant? How many grams of N_2 is formed?   *(10.6 g of N₂)*

Given the following reaction: $2NH_3 + 3CuO ---- > N_2 + 3Cu + 3 H_2O$

5. When a mixture of silver metal and sulphur is heated, silver sulphide is formed:
$$16 Ag_{(s)} + S_{8(s)} -------- > 8 Ag_2S_{(s)}$$
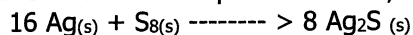
   a) What mass of Ag_2S is produced from the mixture of 2.0 g of Ag and 2.0 g of S_8?
                                                         (2.3 g)

   b) What mass of which reactant is left un-reacted?   *(1.7 g)*

STOICHIOMETRY QUESTIONS INVOLVING PERCENT YIELD

$$AgNO_3 + NaCl \rightarrow AgCl + NaO_3$$

1. When 21.8 g of silver nitrate are reacted with an excess amount of sodium chloride, 17.6 g of silver chloride are formed. If this is a double replacement reaction, calculate the percent yield of silver nitrate.

$$21.8g \times \frac{1mol}{169.9g} \times \frac{1AgCl}{1AgNO_3} \times \frac{143.4g}{1mol} = 18.4g$$

$$17.6/18.4 \times 100 = 95.7\%$$

2. When 5.44 g of copper are reacted with an excess of oxygen, 5.10 g of copper II oxide are formed. Calculate the percent yield of copper II oxide.

$$2Cu + O_2 \rightarrow 2CuO$$

$$5.44g \times \frac{1mol}{63.5g} \times \frac{2CuO}{2Cu} \times \frac{79.5g}{1mol} = 6.81g$$

$$5.10/6.81 \times 100 = 74.9\%$$

3. Ammonia, NH_3, is produced by reacting elemental nitrogen and hydrogen at certain temperatures and pressures to achieve a maximum yield. This process is called the Haber process, after the man who invented it. If 21.9 g of nitrogen are mixed with sufficient hydrogen, then 26.4 g of ammonia are produced. Calculate the percent yield for this reaction.

$$N_2 + 3H_2 \rightarrow 2NH_3$$
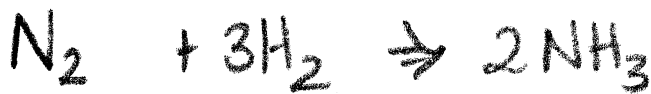
$$21.9g \times \frac{1mol}{28.0g} \times \frac{2NH_3}{1N_2} \times \frac{17.0g}{1mol} = 26.6g \, NH_3$$

$$\frac{26.4g}{26.6g} \times 100 = 99.3\%$$

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