Worksheet #14

Limiting Reagents

1. Potassium superoxide, KO_2, is used in rebreathing masks to generate oxygen according to the reaction below. If the mask contains 0.150 mol KO_2 and 0.100 mol water, how many moles of oxygen can be produced? What is the limiting reagent?

$$4KO_2(s) + 2H_2O(\ell) \rightarrow 4KOH(s) + 3O_2(g)$$

2. Suppose 13.7 g of C_2H_2 reacts with 18.5 g O_2 according to the reaction below. What is the mass of CO_2 produced? What is the limiting reagent?

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

3. Nitrogen gas can react with hydrogen gas to form gaseous ammonia. If 4.7 g of nitrogen reacts with 9.8 g of hydrogen, how much ammonia is formed? What is the limiting reagent?

4. One of the most common acids found in acid rain is sulfuric acid. Sulfuric acid is formed when gaseous sulfur dioxide reacts with ozone (O_3) in the atmosphere to form gaseous sulfur trioxide and oxygen. The sulfur trioxide forms sulfuric acid when it comes in contact with water. If 5.13 g of sulfur dioxide reacts with 6.18 g of ozone, how much sulfur trioxide is formed? What is the limiting reagent?

5. Another way that sulfuric acid is formed in the atmosphere is when sulfur dioxide reacts with oxygen in a reaction catalyzed by dust in the atmosphere to form sulfur trioxide. If 7.99 g of sulfur dioxide reacts with 2.18 g of oxygen, how much sulfur trioxide can form? What is the limiting reagent?

Determining Excess Reactants

6. In the reaction in problem #5 above, how much of the excess reactant remains after all of the limiting reactant has reacted?

7. Heating together the solids NH_4Cl and $Ca(OH)_2$ can generate ammonia. Aqueous $CaCl_2$ and liquid H_2O are also formed. If a mixture of 33.0 g each of NH_4Cl and $Ca(OH)_2$ is heated, how many grams of NH_3 will form? What is the limiting reagent? Which reactant remains in excess, and in what mass?

8. Nitrogen monoxide is formed primarily in car engines, and it can react with oxygen to form gaseous nitrogen dioxide. Nitrogen dioxide forms nitric acid when it comes in contact with water, another component of acid rain. If 3.13 g of nitrogen monoxide reacts with 4.16 g of oxygen, how much nitrogen dioxide will form? What is the limiting reagent? Which reactant remains in excess, and in what mass?

Percent Yield

9. Liquid nitroglycerine ($C_3H_5(NO_3)_3$) is a powerful explosive. When it detonates, it produces a gaseous mixture of nitrogen, water, carbon dioxide, and oxygen. What is the theoretical yield of nitrogen 5.55 g of nitroglycerine explodes? If the actual amount of nitrogen obtained is 0.991 g, what is the percent yield of nitrogen?

10. Solid copper(I) oxide reacts with oxygen to form copper(II) oxide. If 4.18 g of copper(I) oxide reacts with 5.77 g of oxygen, what is the theoretical yield of copper(II) oxide? If the actual amount of copper(II) oxide obtained is 4.28 g, what is the percent yield?

11. What is the percent yield of a reaction in which 41.5 g of solid tungsten(VI) oxide reacts with excess hydrogen to produce metallic tungsten and 9.50 mL of water? The density of water is 1.00 g/mL

12. What is the percent yield of a reaction in which 201 g of solid phosphorous trichloride reacts with excess water to form 128 g of aqueous hydrogen chloride and aqueous phosphorous acid, H_3PO_3?

13. When 18.5 g of gaseous methane and 43.0 g of chlorine gas undergo a reaction that has an 80.0% yield, what mass of liquid chloromethane, CH_3Cl, forms? Gaseous hydrogen chloride also forms.

14. When 56.6 g of calcium and 30.5 g of nitrogen undergo a reaction that has a 93.0% yield, what mass of solid calcium nitride forms?

15. How many moles of MnCl can be produced by the reaction of 5.0 mol $KMnO_4$, 3.0 mol $H_2C_2O_4$, and 22 mol HCl?

$$2KMnO_4 + 5H_2C_2O_4 + 6HCl = 2MnCl_2 + 10\ CO_2 + 2KCl + 8H_2O$$

16. How many grams of Fe are produced by reacting 2.00 kg Al with 300 g Fe_2O_3?

$$Fe_2O_3 + 2Al = Al_2O_3 + 2Fe$$

17. How many grams of which reactant are left over in Problem 16?

18. Gaseous H_2S dissociates into H_2 and S gases at very high temperatures: $H_2S = H_2 + S$. When 0.620 g of H_2S was held at 2000º C, it was found that 13 mg of H_2 were produced. What is the percent yield?

19. The first step in the Ostwald process for manufacturing nitric acid is the reaction of ammonia, NH_3, with oxygen, O_2, to produce nitric oxide, NO, and water. The reaction consumes 595 g of ammonia. How many grams of water are produced? Write the balanced equation.

20. Sodium reacts violently with water to produce hydrogen and sodium hydroxide. How many grams of hydrogen are produced by the reaction of 400 mg of sodium with water?

Limiting Reagents

A Limiting Reagent is the reactant that is completely used up in a reaction. This reagent is the one that determines the amount of product formed. Limiting reagent calculations are performed in the same manner as the stoichiometric equations on Worksheet #11. However, with a limiting reagent, you must calculate the amount of product obtained from each reactant (that means doing math/stoichiometry at least twice!). Note that the limiting reagent is not always the lowest number of grams, so you absolutely must do the math twice! The actual amount of product obtained will be the lowest answer from stoichiometry (do not add, average, multiply, etc. – just take the lowest one). Remember to balance the equations! This also might be a good time to review stoichiometry if you are still struggling.

1. $4KO_2(s) + 2H_2O(\ell) \rightarrow 4KOH(s) + 3O_2(g)$

$$molO_2 = 0.150 molKO_2 \left| \frac{3molO_2}{4molKO_2} \right| = 0.113 molO_2$$

$$molO_2 = 0.100 molH_2O \left| \frac{3molO_2}{4molH_2O} \right| = 0.150 molO_2$$

The lowest amount of O_2 obtained by calculation is 0.113 mol. Therefore, only 0.113 mol O_2 can be obtained. KO_2 is the reagent that is totally consumed in the reaction, and so KO_2 is the limiting reagent (this is the reagent that led to the lowest number of moles of O_2).

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

$$mass(g)CO_2 = 13.7 gC_2H_2 \left| \frac{1molC_2H_2}{26.036g} \right| \frac{4molCO_2}{2molC_2H_2} \left| \frac{44.01g}{1molCO_2} \right| = 46.3 gCO_2$$

$$mass(g)CO_2 = 18.5 gO_2 \left| \frac{1molO_2}{32.00g} \right| \frac{4molCO_2}{5molO_2} \left| \frac{44.01g}{1molCO_2} \right| = 20.4 gCO_2$$

The amount of CO_2 obtained is 20.4 g and oxygen is the limiting reagent (note that there was a higher number of grams of oxygen, but it is still the limiting reagent!).

3. $\_N_2(g) + \underline{3}H_2(g) \rightarrow \underline{2}NH_3(g)$

$$mass(g)NH_3 = 4.7 gN_2 \left| \frac{1molN_2}{28.02g} \right| \frac{2molNH_3}{1molN_2} \left| \frac{17.034g}{1molNH_3} \right| = 5.7 gNH_3$$

$$mass(g)NH_3 = 9.8 gN_2 \left| \frac{1molH_2}{2.016g} \right| \frac{2molNH_3}{3molH_2} \left| \frac{17.034g}{1molNH_3} \right| = 5.5 gNH_3$$

The amount of NH_3 obtained is 5.7 g, and N_2 is the limiting reagent.

4. $\_SO_2(g) + \_O_3(g) \rightarrow \_SO_3(g) + \_O_2(g)$

$$mass(g)SO_3 = 5.13gSO_2\left|\frac{1molSO_2}{64.07g}\right|\frac{1molSO_3}{1molSO_2}\left|\frac{80.07g}{1molSO_3}\right| = 6.41gSO_3$$

$$mass(g)SO_3 = 6.18gO_3\left|\frac{1molO_3}{48.00g}\right|\frac{1molSO_3}{1molO_3}\left|\frac{80.07g}{1molSO_3}\right| = 10.3gSO_3$$

The amount of SO_3 obtained is 6.41 g, and SO_2 is the limiting reagent.

5. $\underline{2}SO_2(g) + \_O_2(g) \rightarrow \underline{2}SO_3(g)$

$$mass(g)SO_3 = 7.99gSO_2\left|\frac{1molSO_2}{64.07g}\right|\frac{2molSO_3}{2molSO_2}\left|\frac{80.07g}{1molSO_3}\right| = 9.99gSO_3$$

$$mass(g)SO_3 = 2.18gO_3\left|\frac{1molO_2}{32.00g}\right|\frac{2molSO_3}{1molO_2}\left|\frac{80.07g}{1molSO_3}\right| = 10.9gSO_3$$

The amount of SO_3 obtained is 9.99 g, and SO_2 is the limiting reagent.

Determining Excess Reagents

The reagent that is not the limiting reagent is the reagent in excess. In other words, we have plenty of it left over when the reaction is completed.

6. The excess reagent is O_2. First, we must determine how much of it was used in the reaction:

$$mass(g)O_2 = 9.99gSO_3\left|\frac{1molSO_3}{80.07g}\right|\frac{1molO_2}{2molSO_3}\left|\frac{32.00g}{1molO_2}\right| = 2.00g$$

Now, subtract the amount used from the amount of oxygen we started with to get the amount left over: 2.18 g O_2 – 2.00 g O_2 = 0.18 g O_2 left over.

7. $\underline{2}NH_4Cl(s) + \_Ca(OH)_2(s) \rightarrow \underline{2}NH_3(g) + \_CaCl_2(aq) + \underline{2}H_2O(\ell)$

First, we must determine what the limiting reagent is, as was done above:

$$mass(g)NH_3 = 33.0gNH_4Cl\left|\frac{1molNH_4Cl}{53.492g}\right|\frac{2molNH_3}{2molNH_4Cl}\left|\frac{17.034g}{1molNH_3}\right| = 10.5gNH_3$$

$$mass(g)NH_3 = 33.0gCa(OH)_2\left|\frac{1molCa(OH)_2}{74.096g}\right|\frac{2molNH_3}{1molCa(OH)_2}\left|\frac{17.034g}{1molNH_3}\right| = 15.2gNH_3$$

The amount of NH_3 obtained is 10.5 g, and NH_4Cl is the limiting reagent. The reagent in excess is $Ca(OH)_2$. Before we can determine how much is left over, we have to determine how much we used through stoichiometry.

$$mass(g)Ca(OH)_2 = 10.5gNH_3\left|\frac{1molNH_3}{17.034g}\right|\frac{1molCa(OH)_2}{2molNH_3}\left|\frac{74.096g}{1molCa(OH)_2}\right| = 22.8Ca(OH)_2$$

So, we used 22.8 g $Ca(OH)_2$ in the reaction. The amount of $Ca(OH)_2$ left over is how much we started with minus how much we used:

$$mass(g)Ca(OH)_2 = 33.0g - 22.8g = 10.2gCa(OH)_2$$

So, we have 10.2 g $Ca(OH)_2$ left over at the end of the reaction.

8. $\underline{2}NO(g) + \_O_2(g) \rightarrow \underline{\ 2}NO_2(g)$

$$mass(g)NO_2 = 3.13gNO\left|\frac{1molNO}{30.01g}\right|\frac{2molNO_2}{2molNO}\left|\frac{46.01g}{1molNO_2}\right| = 4.80gNO_2$$

$$mass(g)NO_2 = 4.16gO_2\left|\frac{1molO_2}{32.00g}\right|\frac{2molNO_2}{1molO_2}\left|\frac{46.01g}{1molNO_2}\right| = 12.0gNO_2$$

The amount of NO_2 obtained is 4.80 g, and the limiting reagent is NO. The reagent in excess is O_2. The amount of O_2 used is:

$$mass(g)O_2 = 4.80gNO_2\left|\frac{1molNO_2}{46.01g}\right|\frac{1molO_2}{2molNO_2}\left|\frac{32.00g}{1molO_2}\right| = 1.67gO_2$$

The amount of O_2 left over is:

$$mass(g)O_2 = 4.16g - 1.67g = 2.49gO_2$$

Percent Yield

No reaction, when performed in the lab, gives as much product as stoichiometry says it should. When reporting yields in literature, in addition to stating a gram amount of product obtained, the percent yield is also reported. The percent yield is the actual yield of a reaction expressed as a percent of the theoretical yield. In order to do these equations, you must first do stoichiometry to determine the amount of product you should obtain.

$\%yield = \left(\frac{actual}{theoretical}\right)100$ Where actual means the yield obtained in the lab and theoretical means the amount that stoichiometry said you should have obtained.

9. $\underline{\ \ 4}C_3H_5(NO_3)_3(\ell) \rightarrow \underline{\ 6}N_2(g) + \underline{10}H_2O(g) + \underline{12}CO_2(g) + \_O_2(g)$

$$mass(g)N_2 = 5.55gC_3H_5(NO_3)_3\left|\frac{1molC_3H_5(NO_3)_3}{227.1g}\right|\frac{6molN_2}{4molC_3H_5(NO_3)_3}\left|\frac{28.02g}{1molN_2}\right| = 1.03gN_2$$

$$\%yield = \left(\frac{0.991g}{1.03g}\right)100 = 96.2\%$$

10. $\underline{\ 2}Cu_2O(s) + \_O_2(g) \rightarrow \underline{\ 4}CuO(s)$

$$mass(g)CuO = 4.18gCu_2O\left|\frac{1molCu_2O}{143.1g}\right|\frac{4molCuO}{2molCu_2O}\left|\frac{79.55g}{1molCuO}\right| = 4.65gCuO$$

$$mass(g)CuO = 5.77gO_2\left|\frac{1molO_2}{32.00g}\right|\frac{4molCuO}{1molO_2}\left|\frac{79.55g}{1molCuO}\right| = 57.4gCuO$$

The theoretical yield of CuO is 4.65 g, and Cu_2O is the limiting reagent.

$$\%yield = \left(\frac{4.28g}{4.65g}\right)100 = 92.0\%$$

11. $\_\_WO_3(s) + \underline{3}H_2(g) \rightarrow \_\_W(s) + \underline{3}H_2O(\ell)$

$$vol(mL)H_2O = 41.5gWO_3\left|\frac{1molWO_3}{231.9g}\right|\frac{3molH_2O}{1molWO_3}\left|\frac{18.02g}{1molH_2O}\right|\frac{1mL}{1.00g}\right| = 9.67mLH_2O$$

$$\%yield = \left(\frac{9.50mL}{9.67mL}\right)100 = 98.2\%$$

12. __PCl_3(aq) + $\underline{3}H_2O(\ell)$ $\rightarrow$ $\underline{3}$HCl(aq) + __H_3PO_3(aq)

$$mass(g)HCl = 201gPCl_3\left|\frac{1molPCl_3}{137.32g}\right|\frac{3molHCl}{1molPCl_3}\left|\frac{36.46g}{1molHCl}\right| = 160.gHCl$$

$$\%yield = \left(\frac{128g}{160.g}\right)100 = 80.0\%$$

13. __CH_4(g) + __Cl_2(g) $\rightarrow$ $CH_3Cl(\ell)$ + __HCl(g)

First, find the limiting reagent, and thus the theoretical yield of CH_3Cl:

$$mass(g)CH_3Cl = 18.5gCH_4\left|\frac{1molCH_4}{16.04g}\right|\frac{1molCH_3Cl}{1molCH_4}\left|\frac{50.48g}{1molCH_3Cl}\right| = 58.2gCH_3Cl$$

$$mass(g)CH_3Cl = 43.0gCl_2\left|\frac{1molCl_2}{70.90g}\right|\frac{1molCH_3Cl}{1molCl_2}\left|\frac{50.48g}{1molCH_3Cl}\right| = 30.6gCH_3Cl$$

So, Cl_2 is the limiting reagent, and 30.6 g CH_3Cl is the theoretical yield.

Remembering that $\%yield = \left(\frac{actual}{theoretical}\right)100$, we can solve for actual yield:

$$actual = \frac{\%yield(theoretical)}{100} = \frac{(80.0)(30.6g)}{100} = 24.5g$$

So 24.5 g of CH_3Cl was obtained in the lab from this experiment.

14. $\underline{3}$Ca(s) + __N_2(g) $\rightarrow$ __Ca_3N_2(s)

$$mass(g)Ca_3N_2 = 56.6gCa\left|\frac{1molCa}{40.08g}\right|\frac{1molCa_3N_2}{3molCa}\left|\frac{148.26g}{1molCa_3N_2}\right| = 69.8gCa_3N_2$$

$$mass(g)Ca_3N_2 = 30.5gN_2\left|\frac{1molN_2}{28.02g}\right|\frac{1molCa_3N_2}{1molN_2}\left|\frac{148.26g}{1molCa_3N_2}\right| = 161gCa_3N_2$$

So, Ca is the limiting reagent, and 69.8 g is the theoretical yield of Ca_3N_2.

Remembering that $\%yield = \left(\frac{actual}{theoretical}\right)100,$ we can solve for actual yield:

$$actual = \frac{\%yield(theoretical)}{100} = \frac{(93.0)(69.8g)}{100} = 64.9g$$

15. 1.2 mol $MnCl_2$ (First determine which is limiting:

$$\frac{5.0 \text{ mol } KMnO_4}{2} = 2.5, \quad \frac{3.0 \text{ mol } H_2C_2O_4}{5} = 0.66 \text{ (limiting)}$$

$$\frac{22 \text{ mol HCl}}{6} = 3.7$$

Then solve $? \text{ mol } MnCl_2 = 3.0 \ \cancel{\text{mol } H_2C_2O_4} \cdot \frac{2 \text{ mol } MnCl_2}{\cancel{5 \text{ mol } H_2C_2O_4}}\Big)$

16. 210 g Fe $\Big($First determine which is limiting:

$$\text{mol Al} = 2.00 \ \cancel{\text{kg Al}} \cdot \frac{10^3 \ \cancel{\text{g Al}}}{\cancel{\text{kg Al}}} \cdot \frac{\text{mol Al}}{27.0 \ \cancel{\text{g Al}}} = 74.0 \text{ mol Al}; \quad \frac{74.0 \text{ mol Al}}{2} = 37.0$$

$$\text{mol } Fe_2O_3 = 3.00 \text{ g } \cancel{Fe_2O_3} \cdot \frac{\text{mol } Fe_2O_3}{159.6 \ \cancel{\text{g } Fe_2O_3}} \cdot \frac{1.89 \text{ mol } Fe_2O_3}{1} \ \text{(limiting)}$$

Then solve $? \text{ g Fe} = 300 \ \cancel{\text{g } Fe_2O_3} \cdot \frac{\cancel{\text{mol } Fe_2O_3}}{159.6 \ \cancel{\text{g } Fe_2O_3}}$

$$\cdot \frac{2 \ \cancel{\text{mol Fe}}}{\cancel{\text{mol } Fe_2O_3}} \cdot \frac{55.8 \text{ g Fe}}{\cancel{\text{mol Fe}}}\Big)$$

17. 1.90 kg Al (Since you found in Problem 16 that Fe_2O_3 is limiting and is therefore completely used up, all you need do is find out how much Al is used by the Fe_2O_3 and subtract this amount from the amount of Al you started with.

$$? \text{ g Al} = 300 \ \cancel{\text{g } Fe_2O_3} \cdot \frac{\cancel{\text{mol } Fe_2O_3}}{158.6 \ \cancel{\text{g } Fe_2O_3}} \cdot \frac{2 \ \cancel{\text{mol Al}}}{\cancel{\text{mol } Fe_2O_3}} \cdot \frac{27.0 \text{ g Al}}{\cancel{\text{mol Al}}}$$

= 102 g Al are used.

Since 2000 g Al were present, then 1898 g Al must remain. Rounded off to the correct number of significant figures, this is 1.90 kg.)

18. 35.4% $\Big(? \text{ g } H_2 = 0.620 \ \cancel{\text{g } H_2S} \cdot \frac{\cancel{\text{mol } H_2S}}{34.1 \ \cancel{\text{g } H_2S}} \cdot \frac{\cancel{\text{mol } H_2}}{\cancel{\text{mol } H_2S}} \cdot \frac{2.02 \text{ g } H_2}{\cancel{\text{mol } H_2}}$

= 0.0367 g H_2 theoretical

$$\text{Percent yield} = \frac{13 \ \cancel{\text{mg } H_2} \cdot \frac{10^{-3} \text{ g } H_2}{\cancel{\text{mg } H_2}}}{0.0367 \text{ g } H_2} \cdot 100 = 35.4\% \text{ yield}\Big)$$

19. 945 g H_2O ($4NH_3 + 5O_2 = 4NO + 6H_2O$

$$\text{g } H_2O = 595 \ \cancel{\text{g } NH_3} \cdot \frac{\cancel{\text{mol } NH_3}}{17.0 \ \cancel{\text{g } NH_3}} \cdot \frac{6 \ \cancel{\text{mol } H_2O}}{4 \ \cancel{\text{mol } NH_3}} \cdot \frac{18.0 \text{ g } H_2O}{\cancel{\text{mol } H_2O}}$$

= 945 g H_2O)

20. 0.0176 g H_2 ($2Na + 2H_2O = 2NaOH + H_2$

$$? \text{ g } H_2 = 400 \ \cancel{\text{mg Na}} \cdot \frac{10^{-3} \ \cancel{\text{g Na}}}{\cancel{\text{mg Na}}} \cdot \frac{\cancel{\text{mol Na}}}{23.0 \ \cancel{\text{g Na}}} \cdot \frac{\cancel{\text{mol } H_2}}{2 \ \cancel{\text{mol Na}}} \cdot \frac{2.02 \text{ g } H_2}{\cancel{\text{mol } H_2}}$$

= 0.0176 g H_2)