Chemistry 20

Lesson 35 – Limiting Reactants

I. Chemical reactions stop when a reactant runs out

Refer to Nelson pages 320 to 327.

Throughout the Chemistry 20 course you have learned to do stoichiometry in many different contexts – gravimetric/mass stoichiometry, solution stoichiometry, acid/base stoichiometry, and gas stoichiometry. In the problems you worked through there was often an unstated assumption that there was enough of each reactant present to react with one another. If, for example, you were burning a given amount of methane gas, it was assumed that there was enough oxygen present for the methane to completely react with. What would happen if the amount of oxygen is in shorter supply than the given amount of methane? The amount of methane that would combust would be limited by the available oxygen. The oxygen would be the **limiting reactant** (i.e. the amount of available oxygen determines the amount of methane that would react.)

To clarify the concept, imagine two situations. In the first situation you have a piece of paper in a room filled with air. When you light the paper with a match, the paper burns (i.e. the cellulose in the paper reacts with oxygen in the air) until there is no more paper left. The reaction stops when there is no more paper left to react with the remaining oxygen in the air. In this case, the paper is the limiting reactant. In the second situation, imagine you place a similar sized piece of paper in a small glass jar. The paper is ignited and the lid to the jar is screwed down. The reaction continues until the available oxygen in the jar is gone. Some of the paper remains in the jar. In this case, the available oxygen is the limiting reactant.

The main concept is that a chemical reaction will continue until one of the reactants runs out. The reactant that runs out first is referred to as the limiting reactant. However, since we are dealing with molar amounts of reactants combining via a mole ratio, which chemical is the limiting reactant is not always readily apparent. In order to accurately predict the limiting reactant the method we use is:

- Calculate the theoretical yield for each reactant independently. In other words, perform a separate stoichiometric calculation for each reactant.
- The limiting reactant is the one which produces the smallest yield.

Example 1

If 100 mL of 0.25 mol/L hydrochloric acid is mixed with 50 mL of 0.70 mol/L sodium hydroxide solution. What mass of water is produced?

$$HCl_{(aq)} + NaOH_{(aq)} \longrightarrow NaCl_{(aq)} + HOH_{(l)}$$

$c_{HCl} = 0.25\ ^{mol}\!/\!_{L}$ $\quad c_{NaOH} = 0.70\ ^{mol}\!/\!_{L}$ $\quad m_{HOH} = ?$

$v_{HCl} = 0.100\,L$ $\quad v_{NaOH} = 0.050\,L$

First, we calculate the possible yield of water for the given amount hydrochloric acid. Note that for this calculation we totally ignore the amount of sodium hydroxide that is present.

$$m_{HOH} = \frac{0.25\,mol\,HCl}{1L} \times \frac{0.100\,L}{} \times \frac{1\,mol\,HOH}{1\,mol\,HCl} \times \frac{18.02\,g\,HOH}{1\,mol\,HOH} = 0.45\,g$$

Second, we calculate the possible yield of water for the given amount of sodium hydroxide. Note that for this calculation we totally ignore the hydrochloric acid.

$$m_{HOH} = \frac{0.70\,mol\,NaOH}{1L} \times \frac{0.050\,L}{} \times \frac{1\,mol\,HOH}{1\,mol\,NaOH} \times \frac{18.02\,g\,HOH}{1\,mol\,HOH} = 0.63\,g$$

The HCl produced the smallest amount of water. Therefore, the hydrochloric acid ran out before the available sodium hydroxide. HCl is the limiting reactant and the amount of water produced is 0.45 g.

Example 2

A 5.0 g candle ($C_{25}H_{52}$) is placed in an enclosed fume hood which contains 50 L of air at SATP (air is 20% oxygen). How many grams of water vapour will be produced?

$$C_{25}H_{52\,(s)} + 51O_{2(g)} \longrightarrow 25\,CO_{2\,(g)} + 26\,H_2O_{(g)}$$

$m_{C_{25}H_{52}} = 5.0\,g$ $\quad v_{O_2} = 50L \times 0.20 = 10L$ $\quad m_{H_2O} = ?$

$M_{C_{25}H_{52}} = 352.77\ ^{g}\!/\!_{mol}$

First, calculate possible yield of water for the given amount of candle.

$$m_{H_2O} = \frac{5.0g\,C_{25}H_{52}}{} \times \frac{1\,mol\,C_{25}H_{52}}{352.77\,g\,C_{25}H_{52}} \times \frac{26\,mol\,H_2O}{1\,mol\,C_{25}H_{52}} \times \frac{18.02\,g\,H_2O}{1\,mol\,H_2O} = 6.64\,g$$

Second, calculate possible yield of water for the given amount of oxygen.

$$m_{H_2O} = \frac{10L\,O_2}{} \times \frac{1\,mol\,O_2}{24.8\,L\,O_2} \times \frac{26\,mol\,H_2O}{51\,mol\,O_2} \times \frac{18.02\,g\,H_2O}{1\,mol\,H_2O} = 3.70\,g$$

Since the available oxygen produced the smallest amount of water, oxygen is the limiting reactant and the amount of water produced is 3.70 g.

II. Practice problem

1. 40.0 mL of 0.35 mol/L potassium dichromate solution is added to 30.0 mL of 0.50 mol/L lead (II) nitrate solution and a precipitate forms.
   A. Which is the limiting reactant?
   B. If 5.75 g of precipitate is collected, what is the percent error?
   B. What are the remaining ions in solution?
   C. What is the concentration of each remaining ion?

III. Assignment

1. If 88.0 g of oxygen reacts with 9.09 g of hydrogen gas. What mass of water should be produced? If a student collects 73.0 g of water, what is the percent error?

2. A student obtained the following data from a reaction between 8.00 g of $Pb(NO_3)_{2(aq)}$ and 30.0 mL of a 1.50 mol/L rubidium bromide solution:
   mass of filter paper .... 1.21 g
   mass of paper & product .... 6.83 g
   What is the limiting reactant and what is the percent error?

3. A student burned 20.20 g of hydrogen with 150.5 g of oxygen and collected 72.05 g of water. Identify the limiting reactant and calculate the percent error.

4. 100 g of zinc is placed in 750 mL of 4.00 mol/L hydrochloric acid. 184 g of zinc chloride was collected. Identify the limiting reactant and calculate the percent error.

5. 200 mL of 0.500 mol/L sodium phosphate solution and 400 mL of 0.500 mol/L barium nitrate solution are reacted. 25.6 g of precipitate is collected. Identify the limiting reactant and calculate the percent error.

6. 2.362 g of oxygen is available in a reaction vessel to burn 1.30 g of ethane ($C_2H_{6(g)}$). What mass of water vapour should be produced?

7. 5.0 g of lead (II) nitrate is dissolved in 250 mL of a 0.85 mol/L solution of sodium chloride. What mass of precipitate should be produced? What mass of which reactant would not have reacted?

8. 50.0 mL of 0.00100 mol/L barium chloride solution was reacted with 100.0 mL of 0.000500 mol/L silver nitrate solution and 6.50 mg of precipitate was collected. Calculate the percent error.

9. 100 mL of a 0.250 mol/L solution of sulfide ions is combined with 100 mL of a 0.150 mol/L solution of scandium ions. If 1.30 g of precipitate was collected, what is the percent error? Which ion remains in solution and what is its concentration?

10. 15.0 mL of 0.250 mol/L gallium sulfate solution is mixed with 25.0 mL of 0.140 mol/L barium nitrate solution.
    a. What is the mass of the precipitate?
    b. What is the final concentration of the gallium ion?
    c. What is the final concentration of the barium ion?

11. 18.3 mL of 0.250 mol/L calcium iodide solution is mixed with 24.1 mL of 0.313 mol/L lead (II) chlorate solution.
    a. What mass of precipitate should result?
    b. What is the final concentration of the lead ion?
    c. What is the final concentration of the calcium ion?