General Chemistry Lab
Experiment 4

Limiting Reactant

INTRODUCTION

Two factors affect the yield of products in a chemical reaction: (1) the amounts of starting materials (reactants) and (2) the percent yield of the reaction. Many experimental conditions, for example, temperature and pressure, can be adjusted to increase yield of a desired product in a chemical reaction. The reactant determining the amount of product generated in a chemical reaction is called the limiting reactant. Sometimes only a limited amount of the one of the reactants needed for the reaction is available, or perhaps it is easier to carry out a reaction by adding an excess of one of the reactants. The maximum amount of product that can be formed is determined by the amount of reactant that is used up first.

Chemicals react according to fixed mole ratios (stoichiometrically), so only a limited amount of product can form from given amounts of starting materials. To better understand the concept of the limiting reactant, let us look at the situation where a toy store is trying to assemble bicycles. Suppose that each bicycle requires six nuts, six bolts, and six washers. If the shipment of parts includes 60 nuts, 60 washers and only 59 bolts, then the bolts become the limiting factor and only 59 bicycles can be assembled.

In his experiment, the reaction of sodium phosphate dodecahydrate, $Na_3PO_4 \cdot 12H_2O$, and barium chloride dihydrate, $BaCl_2 \cdot 2H_2O$, in an aqueous system produces solid barium phosphate, $Ba_3(PO_4)_2$. The molecular form of the equation for the reaction in aqueous solution is

$$2\ Na_3PO_4 \cdot 12H_2O_{(aq)} + 3\ BaCl_2 \cdot 2H_2O_{(aq)} \rightarrow Ba_3(PO_4)_{2(s)} + 6\ NaCl_{(aq)} + 30\ H_2O_{(l)}$$

The two reactant salts and sodium chloride are soluble in water but barium phosphate is insoluble. The ionic equation for the reaction is

$$6\ Na^+ + 2\ PO_4^{3-} + 24\ H_2O_{(l)} + 3\ Ba^{2+} + 6\ Cl^- + 6\ H_2O_{(l)} \rightarrow Ba_3(PO_4)_{2(s)} + 6\ Na^+ + 6\ Cl^- + 30\ H_2O_{(l)}$$

Presenting only the ions that show evidence of a chemical reaction occurring, i.e., the formation of a precipitate (and removing spectator ions from the equation), the net ionic equation for the observed reaction is

$$2\ PO_4^{3-} + 3\ Ba^{2+} \rightarrow Ba_3(PO_4)_{2(s)}$$

Spectator ions, cations or anions, do not participate in any observable or detectable chemical reaction.

Net ionic equation is an equation that includes only those ions that participate in the observed chemical reaction. From the balanced net ionic equation, 2 moles of phosphate ion (from the 2 mol of $Na_3PO_4 \cdot 12H_2O$, molar mass = 380.12 g/mol, or 760.24 g) react with 3 moles of barium ion (from 3 mol of $BaCl_2 \cdot 2H_2O$, molar mass = 244.27 g/mol, or 732.81 g), if the reaction proceeds to completion. The equation also predicts the formation of 1 mole of $Ba_3(PO_4)_2$ (molar mass = 601.93 g/mol), or 601.93 g.

In this experiment the solid salts $Na_3PO_4 \cdot 12\ H_2O$ and $BaCl_2 \cdot 2\ H_2O$ form a heterogeneous mixture of unknown composition. The mass of the solid mixture is measured and added to water, then insoluble $Ba_3(PO_4)_2$ forms. The $Ba_3(PO_4)_2$ precipitate is collected, via gravity filtration and dried, and its mass is measured.

The **percent composition** of the salt mixture is determined by first testing for the limiting reactant. The limiting reactant for the formation of solid barium phosphate is determined from two precipitation tests of the solution: (1) the solution is tested for an excess of barium ion with a phosphate reagent. The formation of a precipitate indicates the presence of an excess of barium ion (and a limited amount of phosphate ion) in the salt mixture. (2) The solution is also tested for an excess of phosphate ion with a barium reagent. The formation of a precipitate indicates the presence of an excess of phosphate ion (and a limited amount of barium ion) in the salt mixture.

CALCULATIONS

The calculations required for the analysis of the data in this experiment are involved. The question, after collection of all of the data, becomes, "How do I proceed to determine the percent composition of a salt mixture containing the salts $Na_3PO_4 \cdot 12H_2O$ and $BaCl_2 \cdot 2H_2O$ from the data of a precipitation reaction?"

Consider the following example: A 0.942 g sample of the salt mixture is added to water and 0.188 g of $Ba_3(PO_4)_2$, precipitate forms. Tests reveal that $BaCl_2 \cdot 2H_2O$ is the limiting reactant. What is the percent composition of the salt mixture?

- $BaCl_2 \cdot 2H_2O$ is the limiting reactant
- The stoichiometry of the reaction indicates that 1 mole $Ba_3(PO_4)_2$ precipitate requires 3 moles Ba^{2+} and therefore 3 moles $BaCl_2 \cdot 2H_2O$.
- To find the number of grams of $BaCl_2 \cdot 2H_2O$ in the original mixture that produced 0.188 g $Ba_3(PO_4)_2$, the following calculation is performed.

$$0.188\text{g } Ba_3(PO_4)_2 \times 1 \text{ mole } Ba_3(PO_4)_2/601.93\text{g } Ba_3(PO_4)_2 \times 3 \text{ mole } Ba^{2+}/1 \text{ mole } Ba_3(PO_4)_2 = 9.37 \times 10^{-4} \text{ mole } Ba^{2+}$$

$$9.37 \times 10^{-4} \text{ mole } Ba^{2+} \times 1 \text{ mole } BaCl_2 \cdot 2H_2O/1 \text{ mole } Ba^{2+} \times 244\text{g } BaCl_2 \cdot 2H_2O/1 \text{ mole } BaCl_2 \cdot 2H_2O = 0.228 \text{ g } BaCl_2 \cdot 2H_2O$$ is a part of the original salt mixture

The mass of the $Na_3PO_4 \cdot 12H_2O$ in the salt mixture must be the difference between the total mass of the original salt sample and the mass of the $BaCl_2 \cdot 2H_2O$, or (0.942 g - 0.229 g =) 0.713 g.

The percent $BaCl_2 \cdot 2H_2O$ in the salt mixture is

$$0.229 \text{ g}/0.942 \text{ g} \times 100 = 24.3\%\ BaCl_2 \cdot 2H_2O$$

The percent $Na_3PO_4 \cdot 12H_2O$ in the salt mixture is

0.713 g/0.942 g x 100 = 75.7% $Na_3PO_4 \cdot 12H_2O$

PROCEDURE

Part A

1. Weigh a clean, dry 400 mL beaker. Record this mass for Trial 1 on the Report Sheet.
2. Transfer all the unknown salt mixture to the 400-mL beaker and reweigh. Record the mass on the Report sheet. Add 200 mL (±0.2 mL) of deionized water.
3. Stir the mixture with a stirring rod for about 1 minute and then allow the precipitate to settle. Leave the stirring rod in the beaker.
4. Digest the precipitate by covering the beaker with a watchglass and warm the solution (80-90°C) over a hotplate.
5. While the precipitate is being kept warm, proceed to set up the gravity filtration apparatus.
   - Place your initials (in pencil) on a piece of filter paper.
   - Fold the filter paper and tear off its corner. Determine its mass (±0.001 g).
   - Seal the filter paper into the filter funnel with a small amount of deionized water.
   - Discard the deionized water from the receiving flask. Have your instructor inspect your apparatus before continuing.

   Periodically check on the progress of the heating solution.
6. After 30 minutes, remove the heat and allow the precipitate to settle; the solution does not need to cool to room temperature.
7. While the precipitate is settling, heat (80-90°C) about 30 mL of deionized water for use as wash water.
8. Once the supernatant has cleared, while still warm, filter the precipitate. Transfer any precipitate on the wall of the beaker to the filter with the aid of a rubber policeman.
9. Transfer two 50 mL volumes of the filtrate (measure with a graduated cylinder) into separate 100 mL beakers, labeled Beaker I and Beaker II. Save for Part B.
10. Wash the $Ba_3(PO_4)_2$ precipitate on the filter paper with two additional 5 mL portions of warm water.
11. Remove the filter paper and precipitate from the filter funnel.
12. Air-dry the precipitate on the filter paper over the weekend. Return on Monday at your convenience to weigh.
13. Determine the combined mass (±0.001 g) of the precipitate and filter paper. Record.

B. Determination of the Limiting Reactant

1. Add 2 drops of the test reagent 0.5 M $BaCl_2$ to the 50 mL of supernatant liquid in Beaker I. If a precipitate forms, the PO_4^{3-} is in excess and Ba^{2+} is the limiting reactant in the original salt mixture.
2. Add 2 drops of the test reagent 0.5 M Na_3PO_4 to the 50 mL of supernatant liquid in Beaker II. If a precipitate forms, the Ba^{2+} is in excess and PO_4^{3-} is the limiting reactant in the original salt mixture. An obvious formation of precipitate should appear in only one

of the tests.

Disposal: Dispose of the barium phosphate, including the filter paper, in the "Waste Solids" container. Dispose of the waste solutions in the "Waste Liquids" container.

CLEANUP: Rinse each beaker with small portions of warm water and discard in the "Waste Liquids" container. Rinse twice with tap water and twice with deionized water and discard in the sink.

Name ______________________________________
Class ________________________

Prelaboratory Assignment

1. A 1.146 g mixture of the solid salts Na_2SO_4 and $Pb(NO_3)_2$ forms an aqueous solution with the precipitation of $PbSO_4$. The precipitate was filtered and dried, and its mass was determined to be 0.672 g. The limiting reactant was determined to be Na_2SO_4.

   a. Write the molecular form of the equation for the reaction.

   b. Write the net ionic equation for the reaction.

   c. How many moles and grams of Na_2SO_4 are in the reaction mixture?

   d. What is the percent by mass of each salt in the mixture?

2. The $Ba_3(PO_4)_2$ (molar mass = 601.93 g/mol) precipitate that formed from a salt mixture has a mass of 0.667 g. Experimental tests revealed that $Na_3PO_4 \cdot 12H_2O$ (molar mass = 380.12 g/mol) was the limiting reactant in the formation of the precipitate and that $BaCl_2 \cdot 2H_2O$ was the excess reactant in the salt mixture. Determine the mass of $Na_3PO_4 \cdot 12H_2O$ in the salt mixture.

Name ________________________________
Class _____________________________

Data Sheet

Unknown number ___________

Part A

	Trial 1
1. Mass of 400 mL beaker + salt mixture (g)	_______________
2. Mass of empty 400 mL beaker	_______________
3. Mass of salt mixture (#1- #2)	_______________
4. Mass of filter paper + $Ba_3(PO_4)_2$ (g) after drying	_______________
5. Mass of filter paper	_______________
6. Mass of $Ba_3(PO_4)_2$(g) (#4- #5)	_______________

Part B
1. Limiting reactant in salt mixture (write complete formula)

2. Excess reactant in salt mixture (write complete formula)

Data Analysis

1. Moles of $Ba_3(PO_4)_2$ precipitated (mol) ________________
2. Moles of limiting reactant in salt mixture (mol)
   - formula of limiting hydrate ________________
3. Mass of limiting reactant in salt mixture (g)
   - formula of limiting hydrate ________________
4. Mass of excess reactant in salt mixture (g)
   - formula of excess hydrate ________________
5. Percent limiting reactant in salt mixture (%)
   - formula of limiting hydrate ________________
6. Percent excess reactant in salt mixture (%)
   - formula of excess hydrate ________________

Show calculations for the trial below.