<u>***EXPERIMENT 4***</u>

LIMITING REACTANT

(العامل المحدد)

BY

DR. RAKAN TARAWNEH AND PROF. KAMAL MOMANI

General Chemistry Lab 1, Chem 0303105

Chemistry Department Mutah University

Jordan

OBJECTIVES:

- To determine the limiting reactant in a mixture of two soluble salts by a precipitation test.
- To determine the percent composition of a salt mixture

❑ Two factors influence the yield of products in a chemical reaction:

1. *The amount of starting materials (reactants)*
2. *The percent yield* (الانتاجية المئوية): *of the reaction (Not all reactions go 100% to completion)*

= (actual yield / theoretical yield) × 100%

- ✓ Percent yield: the percent of the theoretical yield that was actually obtained.
- ✓ Actual yield (الانتاجية الفعلية): the amount of product actually produced by a chemical reaction.
- ✓ Theoretical yield (الانتاجية النظرية): the amount of product that can be made in a chemical reaction based on the amount of limiting reactant.

Many experimental conditions (temperature and pressure, catalyst…), can be adjusted to increase the yield of a desired product (amount of product) in a chemical reaction, but this depends on the amount of limiting reactant (LR).

-Most industrial processes involve limiting reactant situations

❖ Stoichiometry (الحسابات الكيميائية)

Stoichiometry *is the quantitative relationship between the reactants and products in a balanced chemical equation*

$$aA + bB \rightarrow cC + dD$$

The equation of the chemical reaction shows that substances react in fixed mole ratios.

❖ What is a limiting reactant?

- **Limiting reactant**

  the reactant that is consumed first in a chemical reaction and therefore limits the amount of product that can be formed.

- **Reactant in excess (المتفاعل الزائد)**

  the reactant that occurs in a quantity greater than needed to completely react with the limiting reactant.

(OR the reactant that is left over after the reaction is complete is called the excess reactant.)

❖ Determining the limiting reactant

- ✓ calculate the amount of product (mol or g) formed from each reactant
- ✓ identify the limiting reactant, it is the reactant that will produce the least amount of product.
- ✓ the other reactant is the one in excess

❖ Calculating the amount of the reactant in excess that remains after the reaction

I. calculate the reacted amount of the reactant in excess

II. subtract this amount from the starting (initial) amount of this reactant

❖ Writing net ionic equations

1. write the balanced molecular equation
2. write the ionic equation showing the strong electrolytes completely dissociated into cations and anions.
3. cancel the spectator ions on both sides of the ionic equation to get the net ionic equation

❖ Rules for writing ionic equations

- ✓ strong electrolytes in solution are written in their ionic form
- ✓ weak electrolytes are written in their molecular (un-ionized) form
- ✓ non electrolytes are written in their molecular form
- ✓ insoluble substances (precipitates + gasses) = molecular form
- ✓ the net ionic equation should only include substances that have undergone a chemical change.
- ✓ spectator ions are omitted from the net ionic equation
- ✓ equations must be balanced both in atoms and in electrical charge

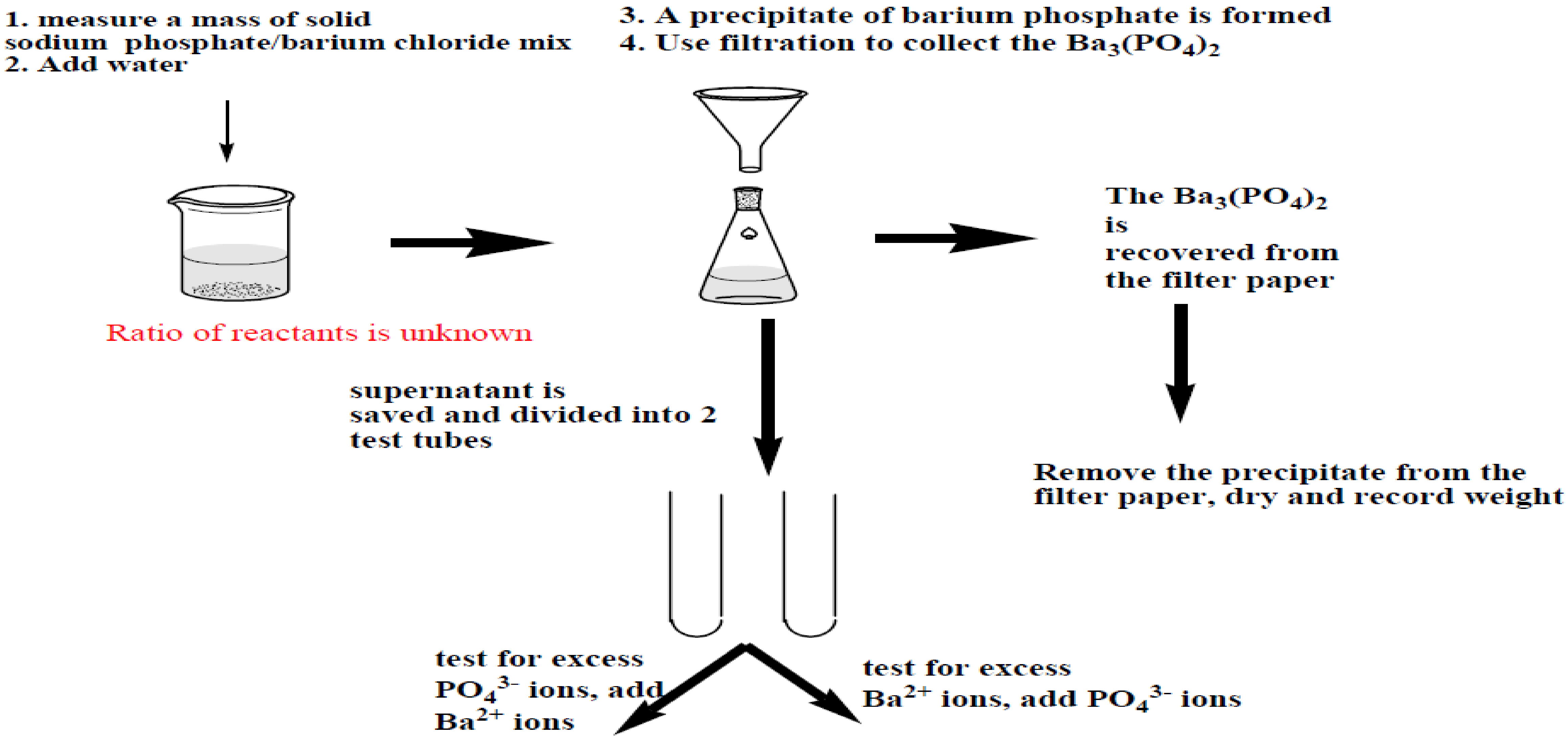
Procedure Overview: In this experiment

1. A measured mass of a solid $Na_3PO_4.12H_2O$ / $BaCl_2.2H_2O$ salt mixture (sample) of unknown composition is added to water.

2. The precipitate (barium phosphate) that forms is digested, filtered, dried, and weighed.

3. Observations from tests on the **supernatant** solution (the liquid left after the solid is removed) determine which salt in the mixture is the limiting reactant.

4. An analysis of the data provides the determination of the percent composition of the salt mixture

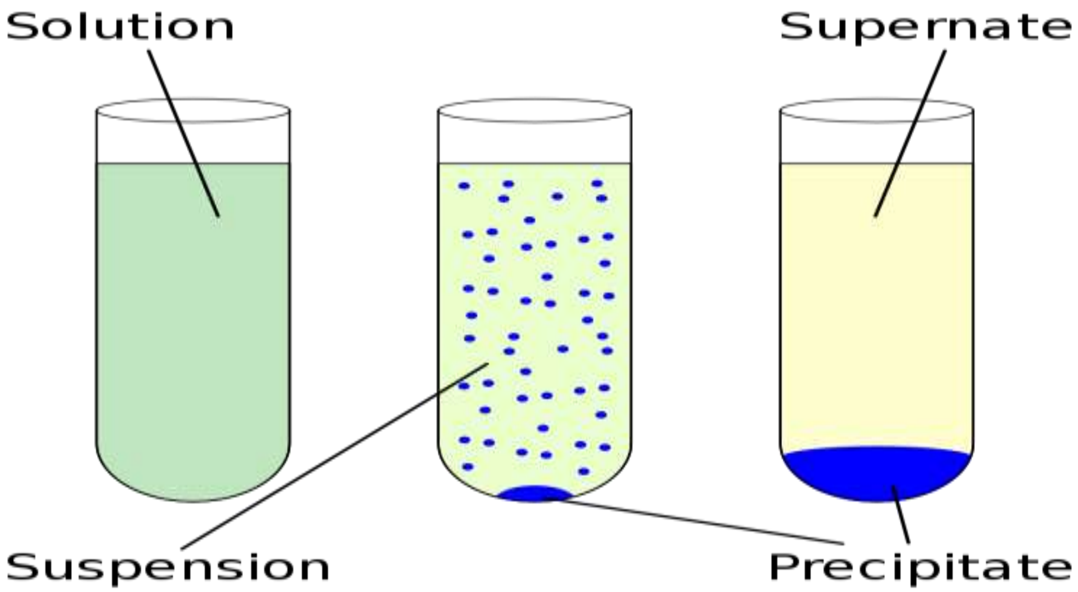


Formation of a precipitate indicates the presence of that ion.
Therefore that ion is present in excess and is not the L.R

Steps of experimental procedure, method of chemical analysis

Step 1. precipitation (الترسيب) of $Ba_3(PO_4)_2$

Transfer 2-3 g of the salt mixture ($Na_3PO_4.12H_2O$ / $BaCl_2.2H_2O$) into 200 mL beaker, add 200 mL deionized water, stir the mixture with stirring rod for about 3 minutes, and the allow the precipitate (ppt) to settle.



Step 2. Digest the Precipitate (هضم الراسب).

✓ Digest the ppt at 80°C (on hot plate or with Bunsen burner) for about 30 minutes, to get larger and purer particles of precipitate, $Ba_3(PO_4)_2$, and then allow the ppt to settle.

✓ If the precipitate is not digested, some particles may be lost in the filtration. Digestion of ppt makes the filtration process more efficient.

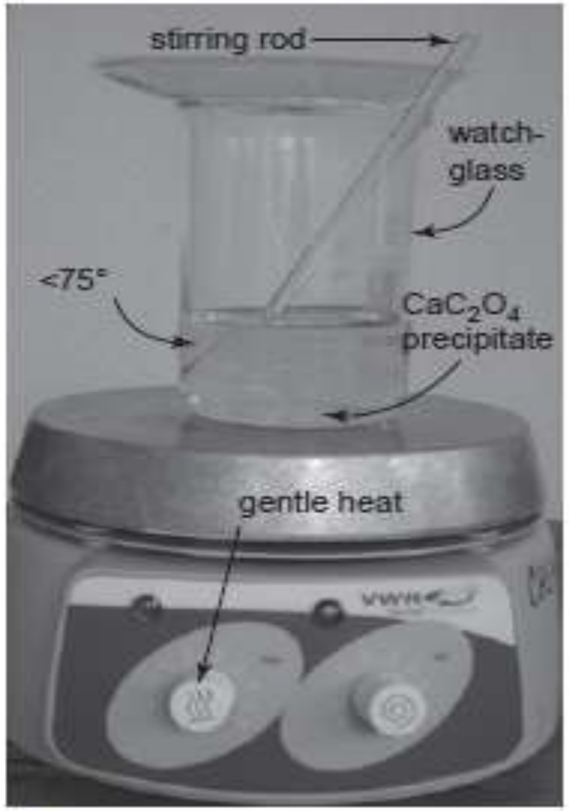


Figure 8.1 Warming and digesting the precipitate.

Step 3. Filter and wash (تصفية وغسل) the ppt with deionized water
(الماء منزوع الأيونات)

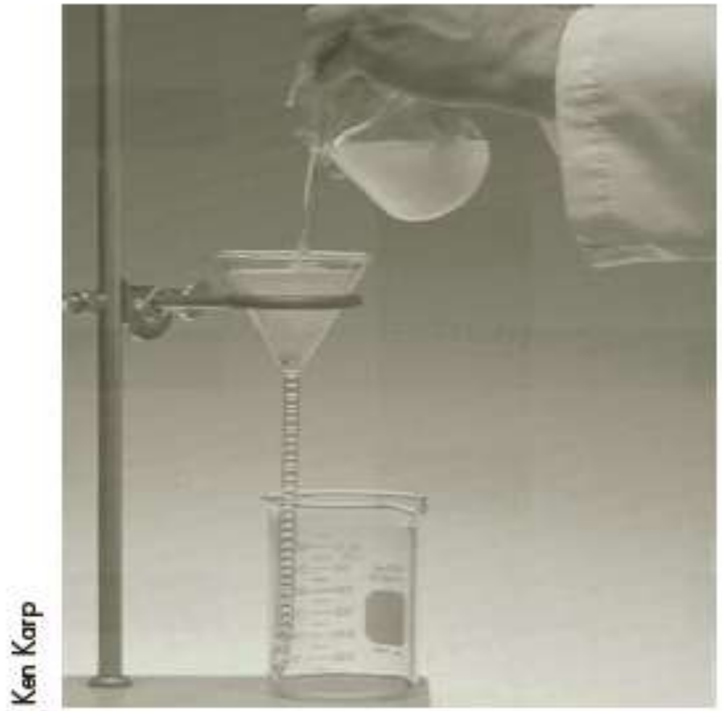


Figure 8.2 Gravity filtration is used to filter finely divided precipitates.

Step 4. Decant supernatant (صب السائل الصافي) into 100 mL beaker to test for limiting reactant (LR).

Step 5. Dry in the oven at 110°C, then weigh the amount of precipitate.

Step 6. Determination of the LR by testing the supernatant (السائل الصافي)

- **Test for excess Ba^{2+}**

Add 3 drops of the test reagent 0.5 *M* Na_3PO_4 to the supernatant liquid in 50 mL test tube 1. If a precipitate forms, the ion *in excess is* **Ba^{2+}** and thus **PO_4^{3-}** is the limiting reactant in the original salt mixture.

THE OPPOSITE IS TRUE

- **Test for excess PO_4^{3-}**

Add 3 drops of the test reagent 0.5 *M* $BaCl_2$ to the supernatant liquid in test tube 2. If a precipitate forms, the ion *in excess is* **PO_4^{3-} and Ba^{2+}** is the limiting reactant in the original salt mixture.

Step 7. Calculation

Calculate the % in the original salt mixture, ($Na_3PO_4.12H_2O$ and $BaCl_2.2H_2O$) **by using the limiting reactant.**

CLEANUP:

Rinse glassware (الأواني الزجاجية), before and immediately after use, twice with tap water and twice with deionized water and discard in the sink.

You may use soap and a brush to clean the glassware

Question. When do expect the precipitate to start in this experiment?

Background Information for Lab

To better understand the concept of the limiting reactant, let's look at the reaction that is under investigation in this experiment: The reaction of sodium phosphate dodecahydrate, $Na_3PO_4.12H_2O$ and barium chloride dihydrate, $BaCl_2.2H_2O$.

The molecular equation (معادلة جزيئية) is:

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

Barium Phosphate is the insoluble product (ppt), while Sodium Chloride remains in solution, see **appendix G**

The ionic equation can be written:

$$6Na^+ + 2PO_4^{3-} + 24H_2O + 3Ba^{2+} + 6Cl^- + 6H_2O \rightarrow Ba_3(PO_4)_{2(s)} + 6Na^+ + 6Cl^- + 30\ H_2O$$

The 'spectator ions (أيونات المتفرج) can be cancelled out, leaving **the net ionic eqn (صافي المعادلة الأيونية)**.

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

- A **spectator ion** is an ion that exists as a reactant and a product in a chemical equation.

The Na^+ and Cl^- ions are spectator ions since they remain unchanged on both sides of the equation. They simply "watch" the other ions react, hence the name. In reaction stoichiometry, spectator ions are removed from a complete ionic equation to form a net ionic equation.

Calculations As In The Following Example:

A 0.942 g sample of salt mixture ($Na_3PO_4.12H_2O$ (molar mass: 380.12 g/mol) and $BaCl_2.2H_2O$ (244.27 g/mol) is added to water and 0.188 g of $Ba_3(PO_4)_2$, (601.96 g/mol) precipitate forms. Tests reveal that $BaCl_2.2H_2O$ is the limiting reactant. What is the % composition of salt mixture?.

Solution (Answer):

- U can solve this question either by using the molecular eqn or the net ionic equation,

The net ionic eqn is $2\ PO_4^{3-}{}_{(aq)} + 3\ Ba^{2+}{}_{(aq)} \rightarrow Ba_3(PO_4)_{2(s)},$ 0.188 g ppt.

- Convert 0.188 g $Ba_3(PO_4)_2$ to g limiting reactant ($BaCl_2.2H_2O$), ???

Mass $BaCl_2.2H_2O$ = ~~0.188 g $Ba_3(PO_4)_2$~~ * (1 ~~mol $Ba_3(PO_4)_2$~~ / 601.96 ~~g $Ba_3(PO_4)_2$~~) *3 ~~mol $BaCl_2.2H_2O$~~/1 ~~mol $Ba_3(PO_4)_2$)~~ * 244.27 g $BaCl_2.2H_2O$/1 ~~mol $BaCl_2.2H_2O$~~

= 0.229 g

- % of $BaCl_2.2H_2O$ in sample = 0.229 / 0.942 x 100 = 24.3%

- Mass of $Na_3PO_4.12H_2O$ in the sample = 0.942 – 0.229 = 0.713
- % of $Na_3PO_4.12H_2O$ in sample = 0.713 / 0.942 x 100 = 75.7%

Experiment 8 Limiting Reactant. *Prelaboratory Assignment*

1. The limiting reactant is determined in this experiment.
   a. What are the reactants (and their molar masses) in the experiment?
   b. What is the product (and its molar mass) that is used for determining the limiting reactant?
   c. Write the molecular eqn and the net ionic eqn
   d. How is the limiting reactant determined in the experiment?

2. Experimental Procedure, Part A.2. What is the procedure and purpose of “digesting the precipitate?

3. Two special steps in the Experimental Procedure are incorporated to reduce the loss of the calcium oxalate precipitate. Identify the steps in the procedure and the reason for each step.

Answer:

Digest the precipitate (ppt) and a fine porosity filter paper is used for filtering the ppt

4. A 0.972-g sample of a $CaCl_2.2H_2O/K_2C_2O_4.H_2O$ solid salt mixture is dissolved in 150 mL of deionized water, previously adjusted to a pH that is basic. The precipitate, after having been filtered and *air-dried*, has a mass of 0.375 g. The limiting reactant in the salt mixture was later determined to be $CaCl_2.2H_2O$.

a. What is the percent by mass of $CaCl_2.2H_2O$ in the salt mixture?
b. How many grams of the excess reactant, $K_2C_2O_4.H_2O$, *reacted* in the mixture?
c. How many grams of the $K_2C_2O_4.H_2O$ in the salt mixture remain *unreacted?*.

Answer:

a. $0.375\text{ g } CaC_2O_4{\bullet}H_2O \times \frac{\text{mol}}{146.12\text{ g}} \times \frac{1\text{ mol } CaCl_2{\bullet}2H_2O}{1\text{ mol } CaC_2O_4{\bullet}H_2O} \times \frac{147.02\text{ g}}{\text{mol}}$

$= 0.377\text{ g } CaCl_2{\bullet}2H_2O$

$\%\ CaCl_2{\bullet}2H_2O = \frac{0.377\text{ g}}{0.972\text{ g}} \times 100 = 38.8\%\ CaCl_2{\bullet}2H_2O$

b. $0.375\text{ g } CaC_2O_4{\bullet}H_2O \times \frac{\text{mol}}{146.12\text{ g}} \times \frac{1\text{ mol } K_2C_2O_4{\bullet}H_2O}{1\text{ mol } CaC_2O_4{\bullet}H_2O} \times \frac{184.24\text{ g}}{\text{mol}}$

$= 0.473\text{ g } K_2C_2O_4{\bullet}H_2O$ that reacts

c. The mass of *excess* $K_2C_2O_4{\bullet}H_2O = 0.972 - (0.377\text{ g} + 0.473\text{ g})$

$= 0.122$ g *excess* $K_2C_2O_4{\bullet}H_2O$

5. 1.009-g mixture of the solid salts Na_2SO_4 (molar mass 142.04 g/mol) and $Pb(NO_3)_2$ (molar mass 331.20 g/mol) forms an aqueous solution with the precipitation of $PbSO_4$ (molar mass 303.26 g/mol). The precipitate was filtered and dried, and its mass was determined to be 0.471 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. How many moles and grams of $Pb(NO_3)_2$ reacted in the reaction mixture?

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

Answer:

a. $Na_2SO_4 + Pb(NO_3)_2 \rightarrow PbSO_4 + 2\,NaNO_3$

b. $Pb^{2+}(aq) + SO_4^{2-}(aq) \rightarrow PbSO_4(s)$

c. $0.471 g\ PbSO_4 \times \frac{mol\ PbSO_4}{303.26\ g} \times \frac{1\ mol\ Na_2SO_4}{1\ mol\ PbSO_4} = 1.55 \times 10^{-3}\ mol\ Na_2SO_4$

$1.55 \times 10^{-3}\ mol\ Na_2SO_4 \times \frac{142.04\ g\ Na_2SO_4}{mol} = 0.221\ g\ Na_2SO_4$

d. $0.471 g\ PbSO_4 \times \frac{mol\ PbSO_4}{303.26\ g} \times \frac{1\ mol\ Pb(NO_3)_2}{1\ mol\ PbSO_4} = 1.55 \times 10^{-3}\ mol\ Pb(NO_3)_2$

$1.55 \times 10^{-3}\ mol\ Pb(NO_3)_2 \times \frac{331.20\ g\ Na_2SO_4}{mol} = 0.514\ g\ Pb(NO_3)_2$ *reacted*

e. $\frac{0.221\ g\ Na_2SO_4}{1.009\ g\ sample} \times 100 = 21.9\%\ Na_2SO_4;\ 78.1\%\ Pb(NO_3)_2$

Post Laboratory Questions:

1. Diborane, B_2H_6, can be produced by the following reaction:

$$NaBH_{4(aq)} + H_2SO_{4(aq)} \rightarrow H_{2(g)} + Na_2SO_{4(aq)} + B_2H_{6(g)}$$

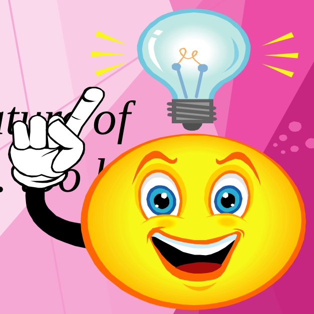
What is the maximum quantity, in grams, of B_2H_6 that can be prepared starting with 250. mL of 0.0875 M H_2SO_4 and 1.55g of $NaBH_4$?.

2. Part A.2. If the step for digesting the precipitate were omitted, what would be the probable consequence of reporting the "percent limiting reactant" in the salt mixture? Explain.

Answer:

Too low. If the CaC_2O_4 precipitate were not digested, more would be lost through the filtering process—less product would infer less limiting reactant in the initial sample mixture.

3. Part A.6, 7. The drying oven, although thought (and assumed) to be set at 125C, had an inside temperature of 84C.How will this error affect the reported percent by mass of the limiting reactant in the salt mixture . . . too high, too low, or unaffected? Explain.



Answer:

Too high. An erred mass that is too high infers a greater mass of limiting reactant in the salt mixture. The percent limiting reactant will be reported too high.