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Determining the Stoichiometry of Chemical Reactions

AP Chemistry Laboratory #9

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Introduction

Double replacement reactions are generally considered to be irreversible. The formation of an insoluble precipitate provides a driving force that makes the reaction proceed in one direction only. The purpose of this laboratory is to find the optimum mole ratio for the formation of a precipitate in a double replacement reaction and use this information to predict the chemical formula of the precipitate.

Concepts

- Stoichiometry
- Mole ratio
- Double replacement reaction

Discussion

A balanced chemical equation gives the mole ratios of reactants and products for chemical reactions. If the formulas of all reactants and products are known, it is relatively easy to balance an equation to find out what these mole ratios are. When the formulas of the products are not known, experimental measurements must be made to determine the ratios.

This laboratory uses the method of continuous variations to determine the mole ratio of two reactants. Several steps are involved. First, solutions of the reactants are prepared in which the concentrations are known. Second, the solutions are mixed a number of times using different ratios of reactants. Third, some property of the reaction that depends on the amount of product formed or on the amount of reactant that remains is measured. This property may be the color intensity of a reactant or product, the mass of a precipitate that forms, or the volume of a gas evolved.

In the method of continuous variations, the total number of moles of reactants is kept constant for the series of measurements. Each measurement is made with a different *mole ratio* of reactants. The optimum ratio, which is the *stoichiometric* ratio in the equation, should consume the greatest amount of reactants, form the greatest amount of product, and, if the reaction is exothermic, generate the most heat and maximum temperature change.

In this laboratory, the amount of precipitate formed in a *double replacement reaction* is the property that will be measured. Seven different mole ratios of reactants are added to 50-mL graduated cylinders. The volume of precipitate formed for each mole ratio is measured and these volumes are plotted versus the mole ratio. The graph will resemble Figure 1.

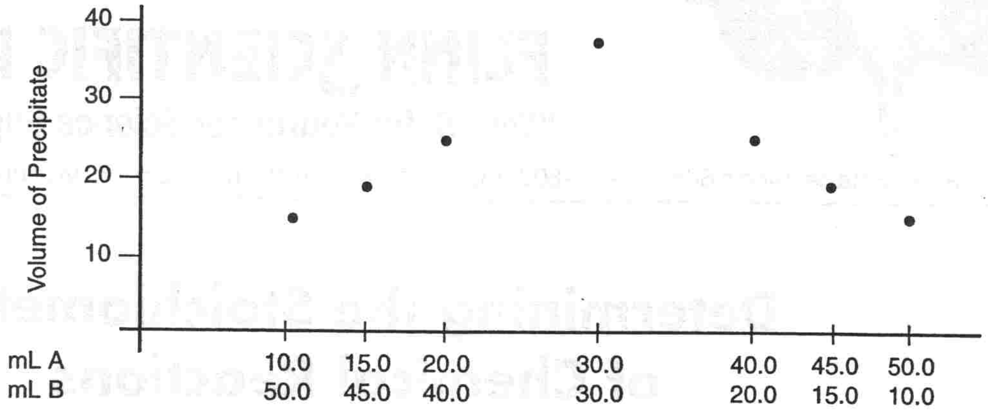

Figure 1.

When two best-fit straight lines are drawn through the increasing and decreasing points on the graph, the intersection yields the optimum mole ratio for the reaction.

Pre-Lab Questions

1. The following values were obtained in a continuous variations experiment designed to find the coefficients in the equation for the reaction between 0.5 M solutions of $AgNO_3$ and K_2CrO_4. One of the products is a precipitate:

Experiment	mL $AgNO_3$	mL K_2CrO_4	Grams Precipitate
1	5.0	45.0	1.7
2	15.0	35.0	5.0
3	25.0	25.0	8.3
4	30.0	20.0	10.0
5	35.0	15.0	9.9
6	40.0	10.0	6.6
7	45.0	5.0	3.3

Plot the mL of $AgNO_3$ versus grams precipitate on graph paper. Label axes and space the data so that the graph reflects the precision of the values given. Use a ruler to draw two best-fitting straight lines through the increasing and decreasing data points. Determine the stoichiometry of the reaction from the intersection of these lines.

______ $AgNO_3$ + ______ K_2CrO_4 → Products

2. Are there enough values to make a valid conclusion? Why or why not?

Materials

Cupric chloride solution, $CuCl_2$, 0.05 M, 210 mL
Ferric nitrate solution, $Fe(NO_3)_3$, 0.1 M, 210 mL
Sodium hydroxide solution, NaOH, 0.1 M, 210 mL
Sodium phosphate, tribasic, solution, Na_3PO_4, 0.05 M, 210 mL
Graduated cylinders, 50-mL, 2
Graduated cylinders, 100-mL, 7
Stirring rods, long, 2
Marker or labeling pen

Safety Precautions

Cupric chloride, ferric nitrate, sodium hydroxide, and trisodium phosphate solutions are skin and eye irritants and are slightly toxic by ingestion. Avoid contact with eyes and skin. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

Part 1. Reaction of Ferric Nitrate with Sodium Hydroxide

The iron in iron nitrate acts as a Lewis acid in solution. When combined with sodium hydroxide, the precipitate formed remains insoluble as long as iron nitrate is not in excess of the stoichiometric mole ratio. When iron nitrate is in excess, the precipitate will begin to dissolve. The larger the excess, the greater the amount of precipitate that dissolves. Your plot of the data will reflect this.

1. Label seven 100-mL graduated cylinders 1–7.
2. Using a clean, 50-mL graduated cylinder, add the appropriate volume of ferric nitrate solution to each 100-mL graduated cylinder, as shown in Table 1.
3. Use a second 50-mL graduated cylinder to add the appropriate volume of sodium hydroxide solution to each 100-mL graduated cylinder, as shown in Table 1.

Table 1.

Cylinder	1	2	3	4	5	6	7
$Fe(NO_3)_3$, 0.1 M, mL	5	10	12	15	17	20	24
NaOH, 0.1 M, mL	55	50	48	45	43	40	36
Fe:OH Mole Ratio	1:11	1:5	1:4	1:3	2:5	1:2	2:3

4. Use a large stirring rod to thoroughly mix the reactants. Observe the signs of chemical reaction in each cylinder. (Mixing the yellow-orange solution of ferric nitrate with the colorless sodium hydroxide solution gives a rust-colored precipitate and a pale yellow supernatant.)
5. Let the reaction mixtures sit undisturbed for at least 10 minutes to allow the precipitates to settle.
6. After the precipitates have settled, record the volume of precipitate in each graduated cylinder in the Part 1 Data Table.

Part 2. Reaction of Cupric Chloride with Sodium Phosphate

1. Label seven clean 100-mL graduated cylinders 1–7.
2. Using a clean, 50-mL graduated cylinder, add the appropriate volume of cupric chloride solution to each 100-mL graduated cylinder, as shown in Table 2.
3. Use a second 50-mL graduated cylinder to add the appropriate volume of sodium phosphate solution to each 100-mL graduated cylinder, as shown in Table 2.

Table 2.

Cylinder	1	2	3	4	5	6	7
$CuCl_2$, 0.05 M, mL	10	20	24	30	36	40	50
Na_3PO_4, 0.05 M, mL	50	40	36	30	24	20	10
Cu:PO_4 Mole Ratio	1:5	1:2	2:3	1:1	3:2	2:1	5:1

4. Use a large stirring rod to thoroughly mix the reactants. Observe the signs of chemical reaction in each cylinder. (Mixing the blue solution of cupric chloride with the colorless sodium phosphate solution gives an aqua-colored precipitate and a colorless supernatant.)
5. Let the reaction mixtures sit undisturbed for at least 10 minutes to allow the precipitates to settle.
6. After the precipitates have settled, record the volume of precipitate in each graduated cylinder in the Part 2 Data Table.

Data Tables

Part 1.

Cylinder	1	2	3	4	5	6	7
$Fe(NO_3)_3$, 0.1 M, mL	5	10	12	15	17	20	24
NaOH, 0.1 M, mL	55	50	48	45	43	40	36
Fe:OH Mole Ratio	1:11	1:5	1:4	1:3	2:5	1:2	2:3
Volume Precipitate (mL)							

Part 2.

Cylinder	1	2	3	4	5	6	7
$CuCl_2$, 0.05 M, mL	10	20	24	30	36	40	50
Na_3PO_4, 0.05 M, mL	50	40	36	30	24	20	10
Cu:PO_4 Mole Ratio	1:5	1:2	2:3	1:1	3:2	2:1	5:1
Volume Precipitate (mL)							

Post-Lab Calculations and Questions

1. On graph paper, plot the milliliters of reactant #1 versus volume of precipitate for each reaction. For the copper chloride graph, draw the two best-fit straight lines through the data points and determine their point of intersection.

2. For the iron nitrate graph, draw the best-fit line through the ascending data, and a smooth curve through the descending data. Determine their intersection point. From the point of intersection, determine the stoichiometric mole ratio for each reaction. Write out the correct balanced equation for each reaction.

3. Explain how this method allows you to find the mole ratio of reactants.

4. Why must you keep a constant volume of reactants?

5. Is it necessary that the concentrations of the two solutions be the same?

6. What is meant by the term limiting reagent?

7. Which reactant is the limiting reagent along the upward sloping line of your graph? Which is the limiting reagent along the downward sloping line?

8. Why is it more accurate to use the point of intersection of the two lines to find the mole ratio rather than the ratio associated with the greatest volume of precipitate?