1. Le Chatelier's Principle

Introduction

All chemical reactions proceed until equilibrium is reached, provided none of the reactants or the products are removed from the reaction mixture. Le Chatelier's principle describes what happens to an equilibrium after it has been disturbed (Ebbing/Gammon, Sections 15.7, 15.8, and 15.9).

Purpose

You will study the application of Le Chatelier's principle by seeing the effect of the addition of Fe^{3+} and SCN^- to an equilibrium mixture of Fe^{3+}, SCN^-, and $Fe(SCN)^{2+}$; the effect of the addition of an acid to an equilibrium mixture of Ni^{2+}, NH_3, and $Ni(NH_3)_6{}^{2+}$; the effect of the addition of an acid and a base on the equilibrium involving an indicator; the effect of acids and bases on the solubility of $Ca(OH)_2$ in water; and the effect of temperature on an equilibrium mixture of Co^{2+}, Cl^-, and $CoCl_4{}^{2-}$.

New substances

In this experiment you will encounter some substances that you may not have seen before. The reaction between Fe^{3+} and SCN^- (thiocyanate ion) gives $Fe(SCN)^{2+}$. This substance is a deeply colored complex ion. Other complex ions that you will encounter are $Ni(NH_3)_6{}^{2+}$ and $CoCl_4{}^{2-}$. These substances result from the reaction between Ni^{2+} and NH_3 and from the reaction between Co^{2+} and Cl^-, respectively. You will also study an equilbrium involving methyl orange, an indicator. Indicators are discussed in Appendix: Indicators, pH Paper, and pH Meters. Read the second, third, and fourth paragraphs of that appendix to gain an understanding of this indicator.

Concept of the experiment

Le Chatelier's principle can be described in the following way: "When a system in chemical equilibrium is disturbed by a change of temperature, pressure, or a concentration, the system shifts in equilibrium composition in a way that tends to counteract this change of variable" (Ebbing/Gammon, Section 15.7). This statement explains the effects that you will encounter in this experiment.

Procedure

Getting started

1. Obtain 3 small test tubes and a piece of filter paper.
2. Obtain directions for discarding the solutions that you will use in this experiment.

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3. Take care in handling the solutions used in this experiment.

> **CAUTION: Solutions of ammonia, hydrochloric acid, and sodium hydroxide can cause chemical burns in addition to ruining your clothing. Do not use your finger as a stopper when mixing these solutions. If you spill any of these solutions on you, wash the contaminated area thoroughly and report the incident to your laboratory instructor. You may require further treatment.**

Studying the equilibrium of Fe^{3+} and SCN^- with $Fe(SCN)^{2+}$

1. Mark each of the test tubes with an identification number (1, 2, and 3).
2. Add 20 mL of distilled water from a graduated cylinder to a 100-mL beaker. Next add 20 drops of 0.1 *M* $Fe(NO_3)_3$ and 20 drops of 0.1 *M* KSCN to the beaker. The color is due to the $Fe(SCN)^{2+}$ ion. Stir the solution thoroughly.
3. Using a 10-mL graduated cylinder, add 3 mL of this solution to each of the test tubes.
4. Add 20 drops of 0.1 *M* $Fe(NO_3)_3$ to test tube 1. Mix by gentle shaking.
5. Add 20 drops of 0.1 *M* KSCN to test tube 2. Mix by gentle shaking.
6. Add 20 drops of distilled water to test tube 3 and mix. The color of the contents of this tube will serve as your reference.
7. Compare the colors in test tubes 1 and 2 with the color in the reference test tube. The intensity of the color in each test tube will indicate the relative concentration of $Fe(SCN)^{2+}$ in that test tube. For best results, view the test tubes down their lengths against a white paper. Record your observations.

Studying the equilibrium of Ni^{2+} and NH_3 with $Ni(NH_3)_6{}^{2+}$

1. Add 10 drops of 0.1 *M* $Ni(NO_3)_2$ to a clean test tube. Record the color.
2. Add drops of 6 *M* NH_3 until the color changes and intensifies. Record the color.
3. Add drops of 6 *M* HCl until the color changes once again. Record the color. The acid has reacted with NH_3 to form $NH_4{}^+$ ions.

Studying the equilibrium involving methyl orange

1. Mark each of two small beakers with an identification letter (A for acid and B for base).
2. Add 10 mL of distilled water and 4 drops of 6 *M* HCl to the beaker marked A. Swirl.
3. Add 10 mL of distilled water and 4 drops of 6 *M* NaOH to the beaker marked B. Swirl.
4. Add 1 mL of distilled water to a clean test tube. Then add 4 drops of the indicator solution and 2 drops of the dilute acid solution. Shake gently. Record the color.
5. Add drops of the dilute base solution until the color changes. Shake gently. Record the color.

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6. Add drops of the dilute acid solution until the color changes again. Shake gently. Record the color.

Studying the solubility of $Ca(OH)_2$

1. Using a 10-mL graduated cylinder, add 5 mL of 6 *M* NaOH to a small, clean beaker.
2. Rinse the graduated cylinder, then use it to add 5 mL of 1 *M* $Ca(NO_3)_2$ to the same beaker.
3. Stir the mixture thoroughly with a stirring rod. A white precipitate of $Ca(OH)_2$ should be present.
4. Using gravity filtration (described in the Introduction to this manual), filter the mixture. This filtration may require a rather long time. While you are waiting, you may wish to begin your study of the equilibrium involving $CoCl_4^{2-}$.
5. Wash the precipitate on the filter paper with 5 mL of distilled water.
6. With a metal spatula, remove as much of the wet precipitate from the filter paper as you can. Suspend this solid in 10 mL of distilled water in a small, clean beaker.
7. Add 2 mL of 6 *M* HCl and stir the contents of the beaker thoroughly. Record the results.
8. Add 5 mL of 6 *M* NaOH to the beaker. Record the results. You should be able to deduce the identity of the substance that is formed.

Studying the equilibrium of Co^{2+} and Cl^- with $CoCl_4^{2-}$

1. Set up a ring stand with an iron ring. Place a piece of wire gauze on the ring. Adjust the height of the ring so that the wire gauze will be in the hottest part of the flame from a laboratory burner. Do not light the burner until this adjustment has been made.

   CAUTION: Avoid burning your fingers. Do not touch the iron ring or the wire gauze at any time while the flame is being used.

2. Place a small beaker containing distilled water on the wire gauze, and heat the water to a *gentle* boil.
3. Add 5 drops of 0.1 *M* $Co(NO_3)_2$ to a clean test tube. Record the color.
4. Add 5 drops of concentrated HCl (do not use 6 *M* HCl). Shake the test tube gently, and record the color. This is the characteristic color of the $CoCl_4^{2-}$ ion.
5. Add 5 drops of distilled water. Shake gently. Record the color.
6. Place the test tube in the boiling water, and wait a few minutes until the color has changed again. Record the color.
7. Cool the test tube in cold water or ice until the color changes once more. Record the color.

   CAUTION: Make sure that your gas outlet and those of your neighbors are closed before you leave the laboratory.

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Le Chatelier's Principle

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Course:	....	Team members:	....
Section:	....		....
Instructor:	....		....

Prelaboratory assignment

1. Define the following terms:

   a. Chemical equilibrium

   b. Le Chatelier's principle

2. Consider the hypothetical reaction

$$A + B + \text{heat} \rightleftharpoons C + D$$

   What will happen to the concentrations of A, B, C, and D under each of the following conditions?

   a. A catalyst is added to the system, which is at equilibrium.

   b. Either C or D is added to the system, which is initially at equilibrium.

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c. Either C or D is removed from the system, which is initially at equilibrium.

d. Either A or B is added to the system, which is initially at equilibrium.

e. The system, which is initially at equilibrium, is cooled.

f. The system, which is initially at equilibrium, is heated.

3. Consider the equilibrium

$$H_2O(l) + HC_2H_3O_2(aq) \rightleftharpoons H_3O^+(aq) + C_2H_3O_2^-(aq)$$

Why will the addition of NaOH to a solution of acetic acid cause the concentration of the acetate ion ($C_2H_3O_2^-$) to increase?

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4. Write chemical equations that describe the equilibria that you will observe during this experiment.

5. What special safety precautions are cited in this experiment?

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Le Chatelier's Principle

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Results

1. *The equilibrium of Fe^{3+} and SCN^{-} with $Fe(SCN)^{2+}$*

   Compare the colors in the following pairs of test tubes.

   1 and 3:

   2 and 3:

2. *The equilibrium of Ni^{2+} and NH_3 with $Ni(NH_3)_6^{2+}$*

   Color before addition of NH_3:

   Color after addition of NH_3:

   Color after addition of HCl:

3. *The equilibrium involving methyl orange*

   Color after addition of dilute HCl:

   Color after addition of dilute NaOH:

   Color after addition of dilute HCl:

4. *The solubility of $Ca(OH)_2$*

   Give the result obtained when HCl is added to a suspension of $Ca(OH)_2$ in water.

   Give the result obtained when NaOH is added and the identity of the substance that is formed.

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5. *The equilibrium of Co^{2+} and Cl^- with $CoCl_4^{2-}$*

   Initial color:

   Color after addition of HCl:

   Color after addition of H_2O:

   Color after heating:

   Color after cooling:

Questions

1. Use Le Chatelier's principle to explain the different colors found in the following equilibria. Show all chemical reactions.

   a. Fe^{3+}, SCN^-, and $Fe(SCN)^{2+}$

   b. Ni^{2+}, NH_3, and $Ni(NH_3)_6^{2+}$

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c. Methyl orange

2. a. How does Le Chatelier's principle explain the result you obtained when you added HCl to a suspension of $Ca(OH)_2$ in water?

b. How does Le Chatelier's principle explain the result you obtained after the addition of NaOH?

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3. a. Why did the addition of water to the equilibrium involving $CoCl_4^{2-}$ cause the color to change? Think carefully.

b. The formation of $CoCl_4^{2-}$ from Co^{2+} and Cl^- is endothermic. Are the color changes that accompany heating and cooling of the equlibrium mixture in accord with Le Chatelier's principle? Explain.

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