The Determination of K_{eq} for $FeSCN^{2+}$

Classic Chemistry Experiment

FLINN Higher Ed

Catalog No. AP7952

Introduction

For any reversible chemical reaction at equilibrium, the concentrations of all reactants and products are constant or stable. There is no further net change in the amounts of reactants and products unless the reaction mixture is disturbed in some way. The equilibrium constant provides a mathematical description of the position of equilibrium for any reversible chemical reaction. What is the equilibrium constant and how can it be determined?

Concepts

- Chemical equilibrium
- Complex-ion reaction
- Equilibrium constant
- Colorimetry

Background

Any reversible reaction eventually reaches a position of *chemical equilibrium*. In some cases, equilibrium favors products and it appears that the reaction proceeds essentially to completion. The amount of reactants remaining under these conditions is very small. In other cases, equilibrium favors reactants and it appears that the reaction occurs only to a slight extent. Under these conditions, the amount of products present at equilibrium is very small.

These ideas can be expressed mathematically in the form of the equilibrium constant. Consider the following general equation for a reversible chemical reaction:

$$aA + bB \rightleftarrows cC + dD \qquad \textit{Equation 1}$$

The *equilibrium constant*, K_{eq}, for this general reaction is given by Equation 2, where the square brackets refer to the molar concentrations of the reactants and products at equilibrium.

$$K_{eq} = \frac{[C]^c[D]^d}{[A]^a[B]^b} \qquad \textit{Equation 2}$$

The equilibrium constant gets its name from the fact that for any reversible chemical reaction, the value of K_{eq} is a constant at a particular temperature. The concentrations of reactants and products at equilibrium vary, depending on the initial amounts of materials present. The special ratio of reactants and products described by K_{eq} is always the same, however, as long as the system has reached equilibrium and the temperature does not change. The value of K_{eq} can be calculated if the concentrations of reactants and products at equilibrium are known.

The reversible chemical reaction of iron(III) ions (Fe^{3+}) with thiocyanate ions (SCN^-) provides a convenient example for determining the equilibrium constant of a reaction. As shown in Equation 3, Fe^{3+} and SCN^- ions combine to form a special type of combined or "complex" ion having the formula $FeSCN^{2+}$.

$$\underset{\textit{Pale yellow}}{Fe^{3+}(aq)} + \underset{\textit{Colorless}}{SCN^-(aq)} \rightleftarrows \underset{\textit{Blood-red}}{FeSCN^{2+}(aq)} \qquad \textit{Equation 3}$$

The equilibrium constant expression for this reaction is given in Equation 4.

$$K_{eq} = \frac{[FeSCN^{2+}]}{[Fe^{3+}][SCN^-]} \qquad \textit{Equation 4}$$

The value of K_{eq} can be determined experimentally by mixing known concentrations of Fe^{3+} and SCN^- ions and measuring the concentration of $FeSCN^{2+}$ ions at equilibrium. As noted in Equation 3, the reactant ions are pale yellow and colorless, respectively, while the product ions are blood-red. The concentration of $FeSCN^{2+}$ complex ions at equilibrium is proportional to the intensity of the red color.

A special sensor or instrument called a *colorimeter* can be used to measure the absorbance of light by the red ions. The more intense the red color, the greater the absorbance. The wavelength of light absorbed by the red ions is about 450 nm. None of the other ions present in solution absorb light at this wavelength. As long as the same size container is used to measure the absorbance of each solution, the absorbance is directly proportional to the concentration of $FeSCN^{2+}$ ions.

Experiment Overview

The purpose of this experiment is to calculate the equilibrium constant for the reaction of iron(III) ions with thiocyanate ions. The reaction is tested under different conditions to determine if the equilibrium constant always has the same numerical value. There are two parts to the experiment.

In Part A, a series of reference solutions and test solutions are prepared. The reference solutions are prepared by mixing a large excess of Fe^{3+} ions with known amounts of SCN^- ions. According to LeChâtelier's Principle, the large excess of iron(III) ions should effectively convert all of the thiocyanate ions to the blood-red $FeSCN^{2+}$ complex ions. The concentration of $FeSCN^{2+}$ complex ions in the reference solutions is essentially equal to the initial concentration of SCN^- ions. The test solutions are prepared by mixing a constant amount of Fe^{3+} ions with different amounts of SCN^- ions. These solutions contain unknown concentrations of $FeSCN^{2+}$ ions at equilibrium.

In Part B, the absorbances of both the reference solutions and the test solutions are measured by colorimetry. A calibration curve is constructed from the absorption values of the reference solutions. The unknown concentrations of $FeSCN^{2+}$ in the test solutions are calculated by comparing their absorbance readings to the absorbance values of the calibration curve.

Materials

- Iron(III) nitrate, $Fe(NO_3)_3$, 0.200 M, 30 mL† Yello
- Iron(III) nitrate, $Fe(NO_3)_3$, 0.0020 M, 25 mL† orang
- Potassium thiocyanate, KSCN, 0.0020 M, 15 mL
- Potassium thiocyanate, KSCN, 0.0002 M, 20 mL
- Water, distilled or deionized
- Colorimeter sensor or spectrophotometer
- Computer interface system and data collection software, 15*
- Computer or calculator for data collection, 15*
- Beakers or large test tubes, 50-mL, 10
- Cuvets with lids, 6
- Labeling or marking pen
- Pipets, serological-type, 5- or 10-mL, 5
- Pipet bulb or pipet filler
- Stirring rod
- Thermometer
- Tissues or lens paper, lint-free
- Wash bottle

*Not required if spectrophotometer is used.

†Contains 1 M nitric acid as the solvent.

Safety Precautions

Iron(III) nitrate solution contains 1 M nitric acid and is a corrosive liquid; it will stain skin and clothing. Notify the teacher and clean up all spills immediately. Potassium thiocyanate is toxic by ingestion; it can generate poisonous hydrogen cyanide gas if heated strongly. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles and chemical-resistant gloves and apron. Wash hands thoroughly with soap and water before leaving the laboratory.

Pre-Laboratory Assignment

1. "The equilibrium concentration of $FeSCN^{2+}$ ions in each reference solution is essentially equal to the concentration of SCN^- ions in solution before any reaction occurs." Use LeChâtelier's Principle to explain why this statement is true.

2. The five reference solutions in Part A are prepared by mixing the 0.200 M $Fe(NO_3)_3$ solution and the 0.00020 M KSCN solution in the amounts listed in the following table.

Standard	Volume of 0.200 M $Fe(NO_3)_3$ Solution	Volume of 0.0002 M KSCN Solution
Reference solution 1	8.0 mL	2.0 mL
Reference solution 2	7.0 mL	3.0 mL
Reference solution 3	6.0 mL	4.0 mL
Reference solution 4	5.0 mL	5.0 mL
Reference solution 5	4.0 mL	6.0 mL

The concentration of Fe^{3+} ions in the first reference solution (M_2) before any reaction occurs can be calculated using the so-called "dilution equation," as shown below.

$$M_1V_1 = M_2V_2 \qquad \textit{Dilution Equation}$$

M_1 = concentration of solution before mixing = 0.200 M $Fe(NO_3)_3$

V_1 = volume of solution before mixing = 8.0 mL

V_2 = final volume of reference solution after mixing = 8.0 + 2.0 mL = 10.0 mL

$$M_2 = \frac{M_1V_1}{V_2} = \frac{(0.200\text{ M})(8.0\text{ mL})}{(10.0\text{ mL})} = 0.16\text{ M}$$

Use the dilution equation to calculate the concentration of SCN^- ions in the five reference solutions before any reaction occurs. Enter these values in the Reference Solutions Data Table as $[FeSCN^{2+}]$, on page 5.

3. The table below summarizes the volumes of Fe^{3+} and SCN^- stock solutions that will be mixed together to prepare the test solutions in Part A. Use the dilution equation to calculate the concentrations of Fe^{3+} and SCN^- ions in each test solution before any reaction occurs. Enter the results of these calculations in scientific notation in the Test Solutions Data Table, on page 5. *Hint:* The final volume (V_2) of each test solution is 10.0 mL.

Sample	Volume of 0.0020 M $Fe(NO_3)_3$ Solution	Volume of 0.0020 M KSCN Solution	Volume of Distilled Water Added
Test solution 6	5.0 mL	1.0 mL	4.0 mL
Test solution 7	5.0 mL	2.0 mL	3.0 mL
Test solution 8	5.0 mL	3.0 mL	2.0 mL
Test solution 9	5.0 mL	4.0 mL	1.0 mL
Test solution 10	5.0 mL	5.0 mL	0 mL