Determination of the Equilibrium Constant for a Chemical Reaction

Information: When chemical substances react, the reaction typically does not go to completion. Rather, the system goes to some intermediate state in which both the reactants and products have concentrations which do not change with time. Such a system is said to be in chemical equilibrium. When in equilibrium at a particular temperature, a reaction mixture obeys the Law of Chemical Equilibrium, which imposes a condition on the concentrations of reactants and products. This condition is expressed in the equilibrium constant K_c for the reaction.

In this experiment we will study the equilibrium properties of the reaction between iron(III) ions and thiocyanate ions:

$$Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons FeSCN^{2+}(aq)$$

In order to calculate K_c for the reaction, it is necessary to know the concentrations of all ions at equilibrium: $[FeSCN^{2+}]_{eq}$, $[SCN^{-}]_{eq}$, and $[Fe^{3+}]_{eq}$. You will prepare four equilibrium systems containing different concentrations of these three ions. The equilibrium concentrations of the three ions will then be experimentally determined. These values will be substituted into the equilibrium constant expression, shown below, to see if K_c is indeed constant.

$$K_c = \frac{[FeSCN^{2+}]}{[Fe^{3+}][SCN^{-}]}$$

By comparing the absorbance of each equilibrium system, A_{eq}, to the absorbance of a standard solution of known concentration, A_{std}, you can determine $[FeSCN^{2+}]_{eq}$. The $[Fe^{3+}]$ in the standard solution will be 100 times greater than in the equilibrium mixtures. According to LeChatelier's principle, this high concentration forces the reaction far to the right, using up nearly 100% of the SCN^{-} ions. According to the balanced equation, for every one mole of SCN^{-} reacted, one mole of $FeSCN^{2+}$ is produced. Thus $[FeSCN^{2+}]_{std}$ is assumed to be equal to $[SCN]_i$.

Assuming $[FeSCN^{2+}]$ and absorbance are related directly (Beer's Law), the concentration of $FeSCN^{2+}$ for any of the equilibrium systems can be found by:

$$[FeSCN^{2+}]_{eq} = \frac{A_{eq}}{A_{std}} \times [FeSCN^{2+}]_{std}$$

Knowing the $[FeSCN^{2+}]_{eq}$ allows you to determine the concentrations of the other two ions at equilibrium. For each mole of $FeSCN^{2+}$ ions produced, one less mole of both Fe^{3+} ions and SCN^{-} ions will be found in the solution (see the 1:1 ratios of coefficients in the chemical reaction). These values can be determined by:

$$[Fe^{3+}]_{eq} = [Fe^{3+}]_i - [FeSCN^{2+}]_{eq}$$

and

$$[SCN^{-}]_{eq} = [SCN^{-}]_i - [FeSCN^{2+}]_{eq}$$

Materials:

Colorimeter
Thermometer
Cuvettes
Beakers
Test tubes
Pipet or Buret
0.0020 M KSCN
0.0020 M $Fe(NO_3)_3$ (in 1.0 M HNO_3)
0.200 M $Fe(NO_3)_3$ (in 1.0 M HNO_3)

Procedure:

1. Label four large test tubes 1-4. Obtain about 30 ml of 0.0020 M $Fe(NO_3)_3$. Transfer 5.0 ml of this solution into each of the four labeled test tubes. *Caution: $Fe(NO_3)_3$ solutions in this experiment are prepared in 1.0 M HNO_3 and should be handled with care.*
2. Obtain about 25 ml of 0.0020 M KSCN. Transfer 2,3,4, and 5 ml of this solution into test tubes 1-4, respectively.
3. Transfer 3,2,1, and 0 ml of distilled water into test tubes 1-4, respectively, to bring the total volume of each test tube to 10 ml. Mix each solution thoroughly with a stirring rod. Be sure to clean and dry the stirring rod after each mixing. Volumes added to each test tube are summarized below:

Test Tube Number	$Fe(NO_3)_3$ (mL)	KSCN (mL)	H_2O (mL)
1	5	2	3
2	5	3	2
3	5	4	1
4	5	5	0

4. Measure and record the temperature of one of the above solutions to use as the temperature for the equilibrium constant, K_c.
5. In a large test tube labeled "5", obtain 18 ml of 0.200 M $Fe(NO_3)_3$ and 2 ml of 0.0020 M KSCN. Stir thoroughly. This is your standard solution of $FeSCN^{2+}$.
6. Calibrate the colorimeter. (If you are using a spectrophotometer, be sure to let the machine warm up for approximately 20 minutes.) Because the red solutions absorb blue light very well, we will select a wavelength of 470 nm. Place a cuvette ¾ full with distilled water into the sample compartment and adjust to 100 %T.
7. Remove the cuvette with distilled water and replace it with a cuvette ¾ full of the first mixture. Measure the absorbance and record in the table. You may need to convert transmittance to absorbance using: $A = 2 - \log\%T$. Repeat for the other mixtures and the standard. Be sure to clean and dry the cuvette each time you fill it with a new sample.

Processing the Data:

1. YOU MUST SHOW ALL CALCULATIONS!!!!!!

2. Write the K_c expression for the reaction in the table. (It is shown on the first page)

3. Calculate the initial concentration of Fe^{3+}, based on the dilution that results from adding KSCN solution and water to the original 0.0020 M $Fe(NO_3)_3$ solution using the equation below. This should be the same for all four test tubes.

$$[Fe^{3+}]_i = \frac{Fe(NO_3)_3 \text{ ml}}{\text{total ml}} \times (0.0020 \text{ M})$$

4. Calculate the initial concentration of SCN^-, based on its dilution by $Fe(NO_3)_3$ and water. This value will vary for all four test tubes.

$$[SCN^-]_i = \frac{\text{KSCN ml}}{\text{total ml}} \times (0.0020 \text{ M})$$

5. $[FeSCN^{2+}]_{eq}$ is calculated using the formula below. A_{eq} and A_{std} are the absorbance values for the equilibrium and standard test tubes, respectively, and $[FeSCN^{2+}]_{std} = (1/10)(0.0020) = 0.00020$ M. This will need to be calculated for all four test tubes.

$$[FeSCN^{2+}]_{eq} = \frac{A_{eq}}{A_{std}} \times [FeSCN^{2+}]_{std}$$

6. Calculate the concentration of Fe^{3+} at equilibrium for test tubes 1-4.

$$[Fe^{3+}]_{eq} = [Fe^{3+}]_i - [FeSCN^{2+}]_{eq}$$

7. Calculate the concentration of SCN^- at equilibrium for test tubes 1-4.

$$[SCN^-]_{eq} = [SCN^-]_i - [FeSCN^{2+}]_{eq}$$

8. Calculate the K_c values for test tubes 1-4.

9. Determine an average K_c value. How constant were your K_c values?

DATA AND CALCULATIONS

Absorbance	Trial 1	Trial 2	Trial 3	Trial 4
	____	____	____	____

Absorbance of standard (Trial 5)	Temperature
____	____ °C

K_c expression	K_c =			
$[Fe^{3+}]_i$				
$[SCN^-]_i$				
$[FeSCN^{2+}]_{eq}$				
$[Fe^{3+}]_{eq}$				
$[SCN^-]_{eq}$				
K_c value				
Average of K_c values	K_c = ______ at ______ °C			