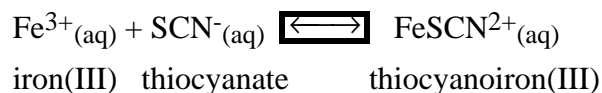# Chemical Equilibrium:
Finding a Constant, K_C

The purpose of this lab is to experimentally determine the equilibrium constant, K_c, for the following chemical reaction:

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

iron(III)   thiocyanate   thiocyanoiron(III)

When Fe^{3+} and SCN^- are combined, equilibrium is established between these two ions and the $FeSCN^{2+}$ ion. 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 to see if K_c is indeed constant.

In order to determine $[FeSCN^{2+}]_{eq}$, you will use the colorimeter shown in Figure 1. The $FeSCN^{2+}$ ion produces solutions with a red color. Because the red solutions absorb blue light very well, the blue LED setting on the colorimeter is used. The computer-interfaced colorimeter measures the amount of blue light absorbed by the colored solutions (absorbance, A). By comparing the absorbance of each equilibrium system, A_{eq}, to the absorbance of a *standard* solution, A_{std}, you can determine $[FeSCN^{2+}]_{eq}$. The standard solution has a known $FeSCN^{2+}$ concentration.
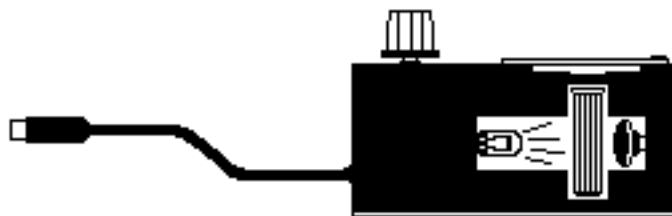

Figure 1

To prepare the standard solution, a very large concentration of Fe^{3+} will be added to a small initial concentration of SCN^- (hereafter referred to as $[SCN^-]_i$. The $[Fe^{3+}]$ in the standard solution is 100 times larger than $[Fe^{3+}]$ 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 Fe^{3+} ions will be found

in the solution (see the 1:1 ratio of coefficients in the equation on the previous page). The $[Fe^{3+}]$ can be determined by:

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

Because one mole of SCN^- is used up for each mole of $FeSCN^{2+}$ ions produced, $[SCN^-]_{eq}$ can be determined by:

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

Knowing the values of $[Fe^{3+}]_{eq}$, $[SCN^-]_{eq}$, and $[FeSCN^{2+}]_{eq}$, you can now calculate the value of K_c, the equilibrium constant.

MATERIALS

Macintosh or IBM-compatible computer	0.0020 M KSCN
Serial Box Interface or ULI	0.0020 M Fe(NO₃)₃ (in 1.0 M HNO₃)
Logger *Pro*	0.200 M Fe(NO₃)₃ (in 1.0 M HNO₃)
Vernier Colorimeter	four pipets
1 plastic cuvette	pipet bulb or pipet pump
five 20 x 150 mm test tubes	three 100-mL beakers
thermometer	tissues (preferably lint-free)

PROCEDURE

1. Obtain and wear goggles.

2. Label four 20 x 150 mm test tubes 1-4. Pour about 30 mL of 0.0020 M $Fe(NO_3)_3$ into a clean, dry 100-mL beaker. Pipet 5.0 mL of this solution into each of the four labeled test tubes. Use a pipet pump or bulb to pipet all solutions. **CAUTION:** *Fe(NO₃)₃ solutions in this experiment are prepared in 1.0 M HNO₃ and should be handled with care.* Pour about 25 mL of the 0.0020 M KSCN into another clean, dry 100-mL beaker. Pipet 2, 3, 4 and 5 mL of this solution into Test Tubes 1-4, respectively. Obtain about 25 mL of distilled water in a 100-mL beaker. Then pipet 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. Measure and record the temperature of one of the above solutions to use as the temperature for the equilibrium constant, K_c. Volumes added to each test tube are summarized below:

Test Tube Number	Fe(NO₃)₃ (mL)	KSCN (mL)	H₂O (mL)
1	5	2	3
2	5	3	2
3	5	4	1
4	5	5	0

3. Prepare a standard solution of $FeSCN^{2+}$ by pipetting 18 mL of 0.200 M $Fe(NO_3)_3$ into a 20 x 150 mm test tube labeled "5". Pipet 2 mL of 0.0020 M KSCN into the same test tube. Stir thoroughly.

4. Prepare the computer for data collection by opening "Exp 20" from the *Chemistry with Computers* experiment files of Logger *Pro*. You should see a live Meter window to display absorbance, and a Table window with columns for the trial number and the absorbance value.

5. You are now ready to calibrate the colorimeter. Prepare a *blank* by filling a cuvette 3/4 full with distilled water. To correctly use a colorimeter cuvette, remember:

   • All cuvettes should be wiped clean and dry on the outside with a tissue.
   • Handle cuvettes only by the top edge of the ribbed sides.
   • All solutions should be free of bubbles.
   • Always position the cuvette with its reference mark facing toward the white reference mark to the right of the cuvette slot on the colorimeter.

   Choose Calibrate from the Experiment menu and then click [Perform No]. Place the blank cuvette in the cuvette slot of the colorimeter and close the lid. Turn the wavelength knob of the colorimeter to the *0% T* position. In this position, the light source is turned off, so no light is received by the photocell. Type "0" in the % edit box. When the displayed voltage reading for Input 1 stabilizes, click [Keep].

   For Reading 2, turn the wavelength knob of the colorimeter to the Blue LED position (470 nm). In this position, the colorimeter is calibrated to show 100% of the blue light being transmitted through the blank cuvette. Type "100" in the % edit box. When the displayed voltage reading for Input 1 stabilizes, click [Keep]., then click [OK].

6. You are now ready to collect absorbance data for the four equilibrium systems and the standard solution. Click [▶Collect]. Empty the water from the cuvette and rinse it twice with ~1-mL portions of the Test Tube 1 solution. Then fill the cuvette 3/4 full with the solution from Test Tube 1. Wipe the outside of the cuvette with a tissue and then place the cuvette in the colorimeter. After closing the lid, wait for the absorbance value displayed in the Meter window to stabilize. Then click [Keep], type "1" (the trial number) in edit box, and press the ENTER key.

7. Discard the cuvette contents as directed by your teacher. Rinse the cuvette twice with the Test Tube 2 solution and fill the cuvette 3/4 full. Follow the procedure in Step 6 to find and record the absorbance of this solution. Type "2" in the edit box and press ENTER.

8. Repeat the Step 6 procedure to find the absorbance of the solutions in Test Tubes 3, 4, and 5 (the standard solution).

9. From the Table window, record the absorbance values for each of the five trials in your Data and Calculations table. Dispose of all solutions as directed by your teacher.

PROCESSING THE DATA

1. In the Data and Calculations table, write the K$_c$ expression for the reaction .

2. 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. See Step 2 of the procedure for the volume of each substance used in Trials 1-4. Calculate $[Fe^{3+}]_i$ using the equation:

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

   This should be the same for all four test tubes.

3. Calculate the initial concentration of SCN⁻, based on its dilution by $Fe(NO_3)_3$ and water:

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

In Test Tube 1, $[SCN^-]_i = (2\ mL\ /\ 10\ mL)(.0020\ M) = .00040\ M$. Calculate this for the other three test tubes.

4. $[FeSCN^{2+}]_{eq}$ is calculated using the formula:

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

where A_{eq} and A_{std} are the absorbance values for the equilibrium and standard test tubes, respectively, and $[FeSCN^{2+}]_{std} = (1/10)(0.0020) = 0.00020\ M$. Calculate $[FeSCN^{2+}]_{eq}$ for each of the four trials.

5. $[Fe^{3+}]_{eq}$: Calculate the concentration of Fe^{3+} at equilibrium for Trials 1-4 using the equation:

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

6. $[SCN^-]_{eq}$: Calculate the concentration of SCN⁻ at equilibrium for Trials 1-4 using the equation:

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

7. Calculate K_c for Trials 1-4. Be sure to show the K_c expression and the values substituted in for each of these calculations.

8. Using your four calculated K_c values, determine an average value for K_c. 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