Chemical Equilibrium: Finding a Constant, K_c

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

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

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.

You will use a Colorimeter to determine $[FeSCN^{2+}]_{eq}$. The $FeSCN^{2+}$ ion produces solutions with a red color. Because the red solutions absorb blue light very well, so Colorimeter users will be instructed to use the 470 nm (blue) LED. Spectrometer users will determine an appropriate wavelength based on the absorbance spectrum of the solution. The light striking the detector is reported as *absorbance* or *percent transmittance*. 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.

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:

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

Knowing the $[FeSCN^{2+}+]_q$ 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:

$$\left[\mathrm{Fe^{3+}}\right]_{eq} = \left[\mathrm{Fe^{3+}}\right]_{i} - \left[\mathrm{FeSCN^{2+}}\right]_{eq}$$

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.

OBJECTIVE

In this experiment, you will determine the equilibrium constant, K_c, for the following chemical reaction:

$Fe^{3+}(aq)$	+	$SCN^-(aq)$	$\leftrightarrow$	$FeSCN^{2+}(aq)$
iron(III)		thiocyanate		thiocyanoiron(III)

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis app
Vernier data-collection interface
Colorimeter
plastic cuvette
five 20 × 150 mm test tubes
three 100 mL beakers
thermometer **or** Temperature Probe
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)
four 10 mL pipets
pipet bulb or pipet pump
tissues (preferably lint-free)

PROCEDURE

1. Obtain and wear goggles.

2. Label four 20 × 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. **DANGER**: $Fe(NO_3)_3$ *solutions in this experiment are prepared in 1.0 M nitric acid solution*, HNO_3. HNO_3 *may intensify fire. Keep away from heat, sparks, open flames, and hot surfaces. Causes severe skin burns and eye damage. Do not breathe mist, vapors, or spray. Avoid contact with acetic acid and readily oxidized substances*.

   Pour about 25 mL of the 0.0020 M KSCN into another clean, dry 100 mL beaker. **WARNING**: *Potassium thiocyanate solution,* KSCN: *Causes eye irritation and mild skin irritation*.

Pipet 2, 3, 4 and 5 mL of the KSCN 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	$Fe(NO_3)_3$ (mL)	KSCN (mL)	H_2O (mL)
1	5	2	3
2	5	3	2
3	5	4	1
4	5	5	0

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

4. Prepare a *blank* by filling a cuvette 3/4 full with 0.0020 M $Fe(NO_3)_3$. To correctly use cuvettes:

   - 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 so the light passes through the clear sides.

5. Connect the Colorimeter to the data-collection interface and then connect the interface to your Chromebook, computer, or mobile device. Launch Graphical Analysis.

6. Calibrate the Colorimeter.

   a. Place the blank in the cuvette slot of the Colorimeter and close the lid.

   b. Press the < or > buttons on the Colorimeter to set the wavelength to 470 nm (blue). Then calibrate by pressing the CAL button on the Colorimeter. When the LED stops flashing, the calibration is complete.

7. Set up the data-collection mode.

   a. Click or tap Mode to open Data Collection Settings. Change Mode to Event Based.

   b. Change Event Mode to Selected Events.

   c. Enter **Trial** as the Event Name and leave the Units field blank. Click or tap Done.

8. You are now ready to collect absorbance data for the four equilibrium systems and the standard solution.

   a. Empty the solution from the cuvette. Using the solution in Test Tube 1, rinse the cuvette twice with ~1 mL amounts and then fill it 3/4 full. Wipe the outside with a tissue and place it in the device. Click or tap Collect to start data collection.
   b. When the value displayed on the screen has stabilized, click or tap Keep. The absorbance and concentration values have now been saved for the first solution.
   c. Discard the cuvette contents as directed. Rinse the cuvette twice with the Test Tube 2 solution, fill the cuvette 3/4 full, and place it in the device. After the reading stabilizes, click or tap Keep.
   d. Repeat the procedure to find the absorbance of the solutions in Test Tubes 3, 4, and 5 (the standard solution).
   e. Click or tap Stop to top data collection. To examine the data pairs on the displayed graph, click or tap the graph. Record the absorbance values for each solution, in your data table. **Note**: You can also adjust the Examine line by dragging the line.
   f. Dispose of all solutions as directed by your instructor.

PROCESSING THE DATA

1. Write the K_c expression for the reaction in the Data and Calculation table.

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

$$[\mathrm{Fe^{3+}}]_\mathrm{i} = \frac{\mathrm{Fe(NO_3)_3\ mL}}{\mathrm{total\ mL}} \times (0.002\ \mathrm{M})$$

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

$$[\mathrm{SCN^-}]_\mathrm{i} = \frac{\mathrm{KSCN\ mL}}{\mathrm{total\ mL}} \times (0.002\ \mathrm{M})$$

   In Test Tube 1, $[SCN^-]_i$ = (2 mL / 10 mL)(0.0020 M) = 0.00040 M. Calculate this for the other three test tubes.

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

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

   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:

$$\left[\mathrm{Fe^{3+}}\right]_\mathrm{eq} = \left[\mathrm{Fe^{3+}}\right]_\mathrm{i} - \left[\mathrm{FeSCN^{2+}}\right]_\mathrm{eq}$$

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				