Thermodynamics and the Solubility of Sodium Tetraborate Decahydrate

In this experiment you, as a class, will determine the solubility of sodium tetraborate decahydrate ($Na_2B_4O_7 \cdot 10\ H_2O$ or $Na_2[B_4O_5(OH)_4] \cdot 8\ H_2O$) at several different temperatures. From this you will determine the thermodynamic variables associated with the dissolution of this salt.

EQUIPMENT

One 250 mL Erlenmeyer flask, 4 125 mL Erlenmeyer flasks, a 5.00 mL volumetric pipette, a magnetic stir bar, a hot plate with a magnetic stirrer, a 50 mL burette, a digital thermometer, an 800 mL or 1000 mL beaker, and a 100 mL beaker

CHEMICALS

About 30 grams of sodium tetraborate decahydrate, bromocresol green indicator solution, standardized 0.5 M HCl solution.

WASTE DISPOSAL

All solutions can go down the drain. All solid waste can go in the trash.

SAFETY

Wear your goggles the entire time. Avoid getting hydrochloric acid on your skin or in your eyes. Do not ingest any of the chemicals.

THEORY

The chemical equation that describes the dissolution of sodium tetraborate decahydrate is:

$$Na_2[B_4O_5(OH)_4] \cdot 8\ H_2O \rightleftarrows 2\ Na^+(aq) + B_4O_5(OH)_4^{2-}(aq) + 8\ H_2O(l)$$

$$K_{sp} = [Na^+]^2[B_4O_5(OH)_4^{2-}]$$

The class will work in pairs, each pair of students measuring the solubility of sodium tetraborate decahydrate at different temperatures. Then we will pool your data for everyone to perform the calculations. You will determine the $[B_4O_5(OH)_4^{2-}]$ in a saturated solution, each pair of students will do this at a different temperature. Because borate is a base, you will be able to find the $[B_4O_5(OH)_4^{2-}]$ by titrating it with dilute hydrochloric acid to the bromocresol green endpoint (bromocresol green is the indicator and will turn from blue to yellow at the endpoint). The balanced equation for the neutralization reaction is:

$$B_4O_5(OH)_4^{2-} + 2HCl + 3H_2O \rightleftharpoons 4\ H_3BO_3 + 2\ Cl^-$$

Because $[Na^+] = 2\ [B_4O_5(OH)_4^{2-}]$ knowing the $[B_4O_5(OH)_4^{2-}]$ from the titration we get K_{sp}:

$$K_{sp} = 4\ [B_4O_5(OH)_4^{2-}]^3$$

For each temperature we will have a K_{sp}, which means we can find ΔG^o for that temperature:

$$\Delta G^o = -RT \ln K_{sp}$$

and since

$$-RT \ln K_{sp} = \Delta H^o - T\Delta S^o$$

or

$$\ln K_{sp} = \left(\frac{-\Delta H^o}{R}\right)\left(\frac{1}{T}\right) + \left(\frac{\Delta S^o}{R}\right)$$

Which means if we plot $\ln K_{sp}$ vs. 1/T (in K) the slope of the best fit straight line will equal $\left(\frac{-\Delta H^o}{R}\right)$ and the y-intercept will equal $\frac{\Delta S^o}{R}$. (ΔH^o and ΔS^o are approximately constant with respect to changes in temperature).

PROCEDURE

Everyone will pair up with a partner. Each pair of students will perform the titration at a different temperature. We will share the data to perfrom the calculations. Make sure you do not transfer undissolved solid when removing a sample of the saturated solution for dilution. Each pair of students will 4 samples of their solution at their temperature.

Weigh about 30 grams of sodium tetraborate decahydrate into a tared 250 mL Erlenmeyer flask. Add about 75 mL of D.I. water and a stir bar.

About half of the pairs will collect data below room temperature and about half above. Follow the appropriate procedure below based on which you are doing. We will decide this in the lab.

Below Room Temperature

Place the solution in an ice water bath with gentle stirring for at least 20 minutes. Make sure all of the solid does not dissolve, if it does add some more and continue stirring.

Turn off the stirrer an place a digital thermometer in the flask and allow it to stand for at least 10 more minutes undisturbed, making sure all of the undissolved solid settles out.

Record the temperature of your solution in your data table.

Using a graduated cylinder carefully transfer 50 mL of the solution (no solid) to a clean 100 mL beaker.

Using your 5.00 mL volumetric pipette remove 4 sample for titration, transferring them to the four 125 mL Erlenmeyer flasks.

To each 125 mL Erlenmeyer flask add about 10 – 15 mL of D.I. water and 3 or 4 drops of the bromocresol green indicator solution. All solutions should turn blue.

Clean your 50 mL burette with D.I. water and rinse with a little of the standardized HCl solution.

Fill the burette with the standardized HCl solution (record the molarity of the HCl in your data table).

CLEAN ALL GLASSWARE EXCEPT THE BURETTE AND 125 mL ERLENMEYER FLASKS WITH WARM WATER! IF YOU DO NOT THEY WILL BE EXTREMELY DIFFICULT TO CLEAN, AND MATT WILL BE VERY UNHAPPY!

Titrate each sample to its endpoint, which is when the solution turns from blue to yellow. Record the initial and final volumes to 2 places past the decimal in your data table. You might have to refill the burette with additional HCl solution. Do not go past the 50.00 mL mark during a titration!

Once you are sure that you are finished add any unused HCl solution to the unused sodium tetraborate solution and add a few drops of bromocresol green indicator solution to the mixture. If the color is yellow add some more sodium tetraborate solution until it is no longer yellow.

Above Room Temperature

Place the solution on a hot plate with gentle stirring until the solution is about 10 ºC above your target temperature.

Clamp your thermometer above the flask with a test tube clamp.

Make sure all of the solid does not dissolve, if it does add some more and continue stirring.

Keep the solution at that temperature for at least 10 minutes making sure that some of the sodium tetraborate remains undissolved.

Turn off the heat and the stirrer and let the solution cool to your target temperature. Additional precipitate will form as the solution cools, this is expected.

Record the temperature of your solution in your data table.

Using a graduated cylinder carefully transfer 50 mL of the solution (no solid) to a clean 100 mL beaker.

Using your 5.00 mL volumetric pipette remove 4 sample for titration, transferring them to the four 125 mL Erlenmeyer flasks.

To each 125 mL Erlenmeyer flask add about 10 – 15 mL of D.I. water and 3 or 4 drops of the bromocresol green indicator solution. All solutions should turn blue.

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CALCULATIONS

1.) Calculate the $[B_4O_5(OH)_4^{2-}]$ in each of the four samples and the average of these.

Record the average $[B_4O_5(OH)_4^{2-}]$ as well as the temperature of your solution in the table on the whiteboard in front of the lab.

2.) For each temperature calculate 1/T (in K^{-1}), K_{sp}, and ln K_{sp}.

3.) Using Excel plot ln K_{sp} (y-axis) vs. 1/T. Have Excel draw the best – fit straight line and give you the equation. Print the graph, including your name in the title and attach it to your lab report in the calculations section.

4.) Calculate ΔH^o and ΔS^o.

5.) Calculate ΔG^o at each of the temperatures.

6.) The accepted value for ΔH^o is +110. kJ/mol and that for ΔS^o is 380. J/K·mol. Calculate the percent error for each of these values.

CONCLUSION

Report the value of K_{sp} at each of the temperatures.

Report the values for ΔH^o and ΔS^o.

Report the value of ΔG^o at each of the temperatures.

Report the percent error for ΔH^{o} and ΔS^{o}.

Comment on the solubility of sodium tetraborate decahydrate with increasing temperature. What role does entropy play?

Discuss at least 2 possible significant sources of error and what effect they would have on the results. Include a discussion of why the source of error would have the proposed result.