## Thermodynamics of Borax Dissolution

## Introduction

Borax, $Na_2B_4O_5(OH)_4{\cdot}8H_2O$, dissolves slightly in water to give sodium ions, a borate ion, and water according to the equation:

$$\underset{\text{Borax}}{Na_2B_4O_5(OH)_4{\cdot}8H_2O_{(s)}} \leftrightarrow 2Na^{1+}_{(aq)} + \underset{\text{Borate}}{B_4O_5(OH)_4{}^{2-}_{(aq)}} + 8H_2O_{(l)}$$

The K expression is: $K = [Na^{1+}]^2[B_4O_5(OH)_4{}^{2-}]$

The above equations can be simplified as :

**(Eq 1)** $Borax_{(s)} \leftrightarrow 2Na^{1+}_{(aq)} + Borate^{2-}_{(aq)}$

**(Eq 2)** $K = [Na^{1+}]^2[Borate^{2-}]$

The concentration of the borate ion can be determined by titration with a standardized HCl solution according to the equation:

**(Eq 3)** $B_4O_5(OH)^{2-}_{(aq)} + 2HCl_{(aq)} + 3H_2O_{(l)} \rightarrow 4H_3BO_{3(aq)} + 2Cl^{1-}_{(aq)}$

The sodium ion concentration will be twice that of the borate ion. (Eq 1)

The HCl solution is standardized by titration with sodium carbonate as follows:

**(Eq 4)** $Na_2CO_{3(aq)} + 2HCl_{(aq)} \rightarrow 2NaCl_{(aq)} + CO_{2(g)}\ H_2O_{(l)}$

By evaluating the K at two temperatures (room temperature and ice bath temperature) the enthalpy ($\Delta H^0$) for the dissolution process can be evaluated from the equation:

**(Eq 5)** $$\ln\left(\frac{K_2}{K_1}\right) = \frac{\Delta H}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

The Gibb's free energy change ($\Delta G^0$) for the dissolution process can be evaluated at each temperature using the equation:

**(Eq 6)** $\Delta G^0 = -RT\ln(K)$

Once $\Delta G^0$ and $\Delta H^0$ are know, the entropy change ($\Delta S^o$) can be evaluated from the Gibb's equation:

**(Eq 7)** $\Delta G^0 = \Delta H^0 - T\Delta S^0$

The enthalpy change and the entropy change should not change with temperature while the Gibb's free energy change will vary with temperature.

## Procedure

### Preparation of Borax-Borate Equilibrium Mixtures

**Room Temperature.** Add 3 grams of solid borax, 50 mL of distilled water and a stir bar to a 100 mL beaker. Place on a magnetic stirrer and stir the mixture for at least 15 minutes. Periodically stop the stirring and **make sure there is undissolved borax present**. If not add some more borax. **There MUST be undissolved solid borax present in order to have equilibrium**.

**Ice Bath temperature**. Add 3 grams of solid borax, 50 mL of distilled water and a stir bar to a second 100 mL beaker. Place this beaker in an ice-water bath and place the bath on a magnetic stirrer and stir for 25-30 minutes. **As above, check to make sure there is undissolved borax present and add some more if necessary.**

### Preparation and Standardization of 0.1M HCl

While the borax systems are equilibrating, prepare and standardize 0.10 M HCl. To a 500 mL Erlenmeyer flask, add about 3 mL of concentrated HCl (12 M) and 350 mL of distilled water. **Be sure to mix the solution well**. Clean a 50 mL buret, rinse it with 5-10 mL of the 0.10 M HCl., and fill it with the prepared 0.10 M HCl solution.

Weigh 0.15 grams of the primary standard $Na_2CO_3$ into two separate Erlenmeyer flasks. Add 50 mL of distilled water and stir to dissolve the solid. Add 4 drops of bromocresol green indicator to give an initial blue solution. Titrate this solution with the HCL to a **yellow color** using a magnetic stirrer. There should be no green tint to the endpoint. Add more of the indicator if the color fades. Do a third titration if the first two do not give reproducible results. Calculate the molarity of the HCl using equation 4.

### Room Temperature Borax $K_2$

About 5 minutes before titrating this mixture, stop the stirring and let the undissolved borax settle. Measure the temperature of the mixture with a Celsius thermometer. Into two separate 125 mL Erlenmyer flasks, pipet a 10.00 mL aliquot of the equilibrium solution. Add 20 mL of distilled water and 4 drops of bromocresol green indicator to give an initial blue color. **Do not pipet any of the solid borax**. Titrate each with the HCl solution to a **yellow endpoint** (no green tint). Do a third titration if the first two do not agree within 1 mL.

### Ice Bath Temperature Borax $K_1$

About 5 minutes before titrating this mixture stop the stirring to let the undissolved borax to settle. Record its temperature. **Keep the mixture in the ice bath until all titrations are complete**. Into two separate125 mLErlenmeyer flasks, pipet 10.00 mL of the equilibrium solution (**no solid**). Add 20 mL of distilled $H_2O$, 4 drops of bromocresol green and titrate to a **yellow endpoint** (no green tint). Do a third titration if necessary.

**Name:**_____

## Data and Results

### HCl Standardization

| | Trial Number 1 | Trial Number 2 | Trial Number 3 (If Necessary) |
|---|---|---|---|
| Mass of $Na_2CO_3$ weighed, g | | | |
| Moles of $Na_2CO_3$ | | | |
| Moles HCl Used (Equation 4) | | | |
| Final mL of HCl | | | |
| Initial mL of HCl | | | |
| mL HCl Used in titration | | | |
| Molarity of HCl | | | |

Average Molarity of HCl _____

**Name:**_____

**Room Temperature Borax $K_2$**

| | Trial Number 1 | Trial Number 2 | Trial Number 3 (If Necessary) |
|---|---|---|---|
| Final mL of HCL | | | |
| Initial mL of HCl | | | |
| mL of HCl Used in titration | | | |
| Molarity of HCl (page 3) | | | |
| Moles HCl Used | | | |
| Moles of Borate (Equation 3) | | | |
| mL of Borate Used (Aliquot taken) | | | |
| Molarity of Borate | | | |
| Molarity of $Na^{1+}$ (Equation 1) | | | |
| $K_2$ of Borax (Equation 2) | | | |

Average $K_2$ of Borax _____

Temperature of borate mixture in: ($t_2$) _____ $^oC$ and $T_2$ _____ K

Remember that the volume of the borate solution is 10.00 mL. Do not include the 20 mL of distilled water added in the titration.

**Name:**_____

## Ice Bath Borax $K_1$

| | Trial Number 1 | Trial Number 2 | Trial Number 3 (If Necessary) |
|---|---|---|---|
| Final mL of HCl | | | |
| Initial mL of HCl | | | |
| mL of HCl Used in titration | | | |
| Molarity of HCl (page 3) | | | |
| Moles HCl Used | | | |
| Moles Borate (Equation 3) | | | |
| mL Borate Used (Aliquot taken) | | | |
| Molarity of Borate | | | |
| Molarity of $Na^{1+}$ (Equation 1) | | | |
| $K_1$ of Borax (Equation 2) | | | |

Average $K_1$ of Borax _____

Temperature of borate mixture in: ($t_1$) _____ $^oC$ and $T_1$ _____ K

Remember the volume of the borate solution titrated is 10.00 mL. Do not include the 20 mL of distilled water added in the titration.

## $\Delta H^0$ of Borax Dissolution

Evaluate the enthalpy change ($\Delta H^0$) for borax dissolution using **equation 5** where $K_2$ is the solubility product constant at room temperature in Kelvin, $T_2$ and $K_1$ is the solubility product constant at ice bath temperature in Kelvin, $T_1$. Show your calculation and report the enthalpy change in **kJ/mol**. R = 8.314 x $10^{-3}$ kJ/mol-K.

**$\Delta H^0$** _____

Name:_____

## $\Delta G^0$ of Borax Dissolution

Calculate free energy change at the two temperatures using **equation 6**.
Show all your work and report the free energy change in **kJ/mol**.
R = 8.314 x $10^{-3}$ kJ/mol-K

**Room temperature.**

**$\Delta G^0$** _____

**Ice Bath temperature.**

**$\Delta G^0$** _____

## $\Delta S^0$ of Borax Dissolution

Calculate the entropy change at the two temperatures using **equation 7**. Show all your work and report the entropy change in **J/mol-K**.

**Room temperature $T_2$**

**$\Delta S^0$**_____

**Ice Bath temperature $T_1$**

**$\Delta S^0$**_____

Average entropy change . _____

**Name:**_____

## Thermodynamics of Borax Dissolution

### Prestudy

1. A 0.1586 gram sample of $Na_2CO_3$ is completely neutralized by 28.45 mL of an HCl solution. Calculate the molarity of the HCl solution using equations from page 1.

2. A 10.00 mL aliquot of a borax-borate equilibrium solution reacts completely with 32.33 mL of a 0.100 M HCl solution. Using the equations on page 1, evaluate the $K_{sp}$ of borax.