**LABORATORY REPORT**

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| ENTHALPY AND ENTROPY OF AN AQUEOUS BORAX SOLUTION |
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| **AIMS/OBJECTIVES:**   1. To measure the enthalpy (∆H) and entropy (∆S) of an aqueous solution of borax (sodium tetraborate decahydrate) from the temperature dependence of the equilibrium constant for the dissolution reaction of borax in water. 2. To study a system of an aqueous solution of borax. 3. To become acquainted with the changes in free energy, enthalpy, and entropy and their relation to the equilibrium constant for a chemical reaction. |
| **INTRODUCTION/THEORY:**  The study a system of a sparingly soluble salt in water provides solubility information, at various temperatures. A variety of other thermodynamic quantities can be determined for the system. Among these thermodynamic quantities are the changes in standard enthalpy, standard entropy, and standard free energy.  Borax dissolves in water into its substituent ions.  i.e. Na2B4O7 • 10H2O(s) ------ 2Na+(aq) + B4O5(OH)42-(aq) + 8H2O(l)  In this experiment, there is always some solid borax remaining in the sample mixture at any temperature below about 65°C. This means that the saturated borax solution begins to precipitate at temperatures below 65°C. That being the case, the 'concentration' of solid borax can be assumed constant, and the equilibrium expression can be simplified:  K = [Na+]2 [B4O5(OH)42-] [H2O]8  The water term in the expression (which was originally part of borax's crystalline matrix) is lost to the sample mixture. This added amount of water does not significantly change the concentration of water already present. The water term can also be 'simplified out' of the equilibrium expression:  *K* = [Na+]2 [B4O5(OH)42-]  A *solubility product constant* (K*sp*) expression for borax in water is thus needed to be obtained. To determine a value for the solubility product, a method must be found to determine either the amount of sodium ion, or borate ion, in the sample mixture. The original equilibrium expression, and balanced solubility equilibrium reaction, leads to a convenient way to express either ion in terms of the other. A series of substitutions, based on the original balanced solubility equilibrium equation, gives the desired K*sp*, expression defined in terms of the borate ion only.  Finding the concentration of borate ion, in any sample at any given temperature, leads directly to a value for solubility product (K*sp*) at that temperature.  Borax is titrated with HCl solution to determine the concentration of borate ion.  B4O5(OH)42-(*aq*) + 2HCl(*aq*) + 3H2O(*l*) -------- 4B(OH)3(*aq*) + 2Cl- (*aq*)  The number of moles of borate ion is determined, and on dividing by the volume of borate ion-containing sample, the concentration of borate ion is obtained. This general procedure is repeated for borate ion-containing samples of constant volume obtained at various temperatures. |
| **CHEMICALS & EQUIPMENT:**   1. Erlenmeyer flask. 2. Test tubes 3. 50.00ml Burette 4. Pipette 5. Laboratory thermometer 6. Burner 7. Beaker 8. Digital analytical balance 9. Solid borax sample   10.Distilled water  11. Heating mantle |
| **PROCEEDURE:**   |  |  | | --- | --- | | **Procedure** | **Observation** | | 1. 5 clean test tubes were labeled and 5.00ml of water was transferred into each test tube with a volumetric pipette. |  | | 1. The exact level of the liquid in the test tube was marked after which the liquid was discarded and the test tube dried. |  | | 1. Approximately 30g of borax was dissolved in a 100mL beaker in 50mL of distilled water. | Not all the borax dissolved.  Formation of a white chalky mixture. | | 1. The mixture was then heated gently to 65oC and a little more borax was added to the solution until excess solid was present and the solution was completely saturated. |  | | 1. The solution was allowed to cool to approximately 60oC and was poured into the test tube #1 until the level of the solution reached the exact 5.00mL mark on the test tube. The exact temperature of the solution was noted. The solution was transferred and titrated with 0.500M HCl.2 drops of Bromocresol green were used as indicator. | Blue colour was observed when the indicator was added.  Light yellowish green colour was observed after the titration. | | 1. The solution was allowed to cool to approximately 50oC and exactly 5.00mL of it was poured into test tube #2. The exact temperature of the solution temperature was noted. The solution was transferred and titrated with 0.500M HCl.2 drops of Bromocresol green were used as indicator. | Blue colour was observed when the indicator was added.  Light yellow colour was observed after the titration. | | 1. The steps were repeated and the solution was cooled to approximately 40oC, 30oC and 20oC in the tubes #3, #4 and #5 respectively. The solution was transferred and titrated with 0.500M HCl.2 drops of Bromocresol green were used as indicator. | Blue colour was observed when the indicator was added.  Light yellow colour was observed after the titration. | |
| **CALCULATIONS:**  *TABLE OF RESULTS*   |  |  |  | | --- | --- | --- | | **Temperature /**oC | **Volume B4O5(OH)45-/ml** | **Volume HCl/ml** | | 60 | 5.0 | 27.00 | | 50 | 5.0 | 25.55 | | 40 | 5.0 | 10.45 | | 30 | 5.0 | 6.70 | | 20 | 5.0 | 5.30 |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | *Temp (oC)* | *T (Kelvin)* | *1/T (Kelvin-1)* | *[Oxalate]* | *Ksp* | *InKsp* | | 60 | 333 | 3.003 x 10-3 | 1.35 | 9.84 | 2.29 | | 50 | 323 | 3.096 x 10-3 | 1.28 | 8.39 | 2.13 | | 40 | 313 | 3.195 x 10-3 | 0.52 | 0.56 | -0.58 | | 30 | 303 | 3.300 x 10-3 | 0.34 | 0.16 | -1.83 | | 20 | 293 | 3.413 x 10-3 | 0.27 | 0.08 | -2.53 |  1. At T = 20oC = 273 + 20 = 293K   T-1 = 293-1 = 3.00 × 10-3 K-1  From reaction equation:  *B4O5(OH)42- (aq) + 2HCl(aq) + 3H2O(l) ------- 4B(OH)3(aq) + 2Cl- (aq)*  n (borate) =1  n (H+) 2  n(borate) = 0.5 × n (H+)  n(H+) = [H+] × volume of H+  = 0.5 × 27.00/1000  = 0.015mol  Hence n (borate) = 0.5 × 0.0135  = **6.75 x 10-3**  C= n/v  Concentration of borax, C ((B4O5(OH)45) = 6.75 x 10-3/0.005  = **1.35M**  Ksp = 4 [borate] 3  = 4 (1.35)3  = **9.84**  InKsp = **2.29**  (2) From graph,  Gradient = Y2 – Y1  X2 – X1  = -2.53 - 2.29 .  3.413 x 10-3– 3.003 x 10-3    = **-11756.1**  But from equation (2), slope = -ΔHo = -11756.1  -ΔH= -11756.1R  R = 8.314J/molK  ΔHo = 8.314 x -11756.1  = **97.74KJ/molK**  3. The two points are:  (3.413 x 10-3, -2.53) and (3.003 x 10-3,2.29)  Substituting into equation (2)  -2.53 = -ΔHo (3.413 x 10-3) + ΔS....... (1)  R R  2.29 = -ΔHo (3.003 x 10-3) + ΔS…... (2)  R R  But R = 8.314 J/mol and multiplying both sides by the value of R  → 8.314(-2.53) = -ΔHo (3.413 x 10-3) + ΔS…... (1)  8.314(2.29) = -ΔHo (3.003 x 10-3) + ΔS…... (2)  (1) – (2)  -21.034 = 0.00014ΔHo  → ΔHo = -150242.86 J/mol  = -150KJ/mol  Substituting ΔHo into (1)  -21.03 = -(3.413 x 10-3 × -150242.86) + ΔS  ΔS = **493.24J/mol**   1. The value of the enthalpy of the dissociation of borax solution from the experiment conducted was   -97.74KJ/mol. Comparing this value to the literature value (110 KJ/mol), it can be noticed that the value has deviated to some extent. This deviation can be attributed to certain factors:   1. Temperature reading. 2. Titre value obtained as a result of poor volume reading as a result of parallax. 3. The nature of the borax solution (it solidifies quickly). 4. Some of the solution clanged to the stirrer which was used as a result not all the 5.00ml borax solution was used in the titration. 5. Recording the amount of acid used for titrating at very low temperatures was impossible due to the room temperature which was higher. 6. From the experiment conducted and the values obtained, it is realized that as the temperature increased, there was an increase in solubility as indicated by the Ksp values and their corresponding temperatures.   On the other hand, when the temperature was decreasing, the borax solution was observed to be solidifying indicating also that a decrease in temperature reduces the solubility. In effect, there is a linear relationship between temperature and solubility.   1. The positive value of ΔHo obtained signifies an endothermic reaction. It was observed during the course of the experiment that beaker was cold to touch until heating and when left standing when the borax was dissolved in water, the system caked and became cold implying an endothermic process taking place. 2. From the calculated value, the entropy of the system is positive. This is so because the entropy of the borax (initial state) is lower than the borax solution (final state). In the reaction, the reactants and products are of the same phase but the number of moles of the products is greater than the number of moles of the reactants which leads to an increase in entropy (positive). |
| **DISCUSSION:**  For a series of borax – containing samples taken at different temperatures, the concentration of borate ions will be determined. The borate ions react with a monoprotic acid such as HCl in a 1:2 fashion:  B4O5 (OH)42-(aq) +2 HCl(aq) + 3 H2O(l) → 4 B (OH)3 (aq) + 2Cl-(aq)  The experiment requires that the solubility of borax be found at various temperatures.  The solubility of the borate ion depends on temperature such that it increases as temperature increases. When equilibrium is established in the saturated solution at a specific temperature, the rate of formation of borate ions is equal to the rate of deposition of the borax. The equilibrium constant for the dissolution of a solid in a solvent is called the solubility product constant (Ksp) which is equal to the product of the concentration of the ions in solution.  Heat is applied to the borate ion in the conical flask so as to allow the full reaction of the borate ions and the HCl in solution.  Recording the amount of acid used for titrating at very low temperatures was impossible due to the room temperature which was higher.  It was observed during the course of the experiment that beaker was cold to touch until heating and when left standing when the borax was dissolved in water, the system caked and became cold implying an exothermic process taking place. |
| **PRECAUTIONS:**   1. At the different temperature readings which were taken, it was ensured that the borax solution did not precipitate by quickly undertaking the titration process. 2. It was also ensured that no solid borax was transferred from the beaker into the test tube. 3. Heat was applied to the borax solution when any precipitation of the borax was observed to prevent solid borax from partaking in the reaction. 4. The apparatus which were used in the experiment were thoroughly and quickly washed clean and dried to prevent making the borax solution impure. 5. Heat tongs were used to transport the hot beaker and test tube from the heat source to the working bench. |
| **CONCLUSION:**  From the experiment conducted and the values obtained, it is realized that as the temperature increased, there was an increase in solubility as indicated by the Ksp values and their corresponding temperatures.  On the other hand, when the temperature was decreasing, the borax solution was observed to be solidifying indicating also that a decrease in temperature reduces the solubility. In effect, there is a linear relationship between temperature and solubility.  The negative value of ΔHo obtained signifies an endothermic reaction.  Bromocresol green as an indicator turn yellow in an acidic region of 3.6-5.2. The colour of the solution changed to light yellow indicating the end point of the reaction. This shows that the indicator was suitable for the experiment. |
| **REFRENCES:**   1. Brown Lemay Bursten, Chemistry the central science, 7th edition, pp. 597,598. 2. Wesley. D. Smith and David. G. Lygre., CHEMISTRY: A contemporary Approach 3. Martin Silberberg, CHEMISTRY: The Molecular Nature of Matter and Change 4. Vogel’s Textbook of Practical Organic Chemistry. |