Experiment 5: Determination of the Solubility Product Constant for Potassium Hydrogen Tartrate

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I. Introduction

The purpose of this experiment was to determine and evaluate the constancy of the solubility product constant (*Ksp*) for potassium hydrogen tartrate (KHT) in various saturated solutions. These values can be found in the conclusion of the report. The product constant represents the dissociation of the compound in water. To achieve this, multiple titrations were performed using phenolphthalein as an indicator. Four saturated solutions of KHT were prepared, each having a total ionic strength of $0.200M$ to minimise the effect of interionic attractions. Additionally, excess potassium was added to three of the solutions to investigate the common ion effect.

II. Experimental

KHT ($KHC_4H_4O_6$) has low solubility in aqueous solutions, as depicted in equation (5.1).

$$KHC_4H_4O_{6(s)} \rightleftharpoons K^+_{(aq)} + HC_4H_4O_6{}^-_{(aq)} \tag{5.1}$$

Moreover, using the abbreviation HT^- for the hydrogen tartrate ion, $HC_4H_4O_6^-$, the net ionic equation is seen in equation (5.2).

$$KHT_{(s)} \rightleftharpoons K^+_{(aq)} + HT^-_{(aq)} \tag{5.2}$$

Furthermore, a saturated solution of KHT contains only the amount of KHT that will dissolve (e.g., ionise) and dissociate. This is generated by allowing the salt to sit in water until it is all dissolved. Later, this solution is filtered to remove any undissolved salt, creating a saturated solution. To determine the solubility of the four saturated solutions, aliquots will be titrated & phenolpthalein will be used as an indicator to mark the endpoint. The complete

& net ionic equation for the titration of the reaction of the saturated KHT solution is seen in equation (5.3).

$$K^{+}_{(aq)} + HT^{-}_{(aq)} + Na^{+}_{(aq)} + OH^{-}_{(aq)} \rightarrow K^{+}_{(aq)} + T^{2-}_{(aq)} + Na^{+}_{(aq)} + H_2O_{(l)} \tag{5.3}$$

$$HT^{-}_{(aq)} + OH^{-}_{(aq)} \rightarrow T^{2-}_{(aq)} + H_2O_{(l)}$$

For further experimental procedures, see the lab manual (Bell & Brinkel, 2014)[1].

Part 1. Solubility of KHT in 0.200*M* NaCl

Approximately 2g of KHT was added to a 250.00mL screw-cap bottle. The actual mass of the salt was recorded in the lab notebook, which was equal to 2.0268g. The bottle was filled halfway with 0.200*M* NaCl & as shook vigorously for two minutes to ensure saturation. Then, it was placed in an ice bath & the flask was continuously swirled to ensure an even temperature concentration. Every 30 seconds, the temperature was checked to make sure that it was within ± 0.5°C of the target temperature of 18°C.

A filtration apparatus was set up using a ring stand, funnel support, & a glass funnel with filter paper inside. The solution was filtered once it was ± 0.5°C of the target temperature of 18°C. It was filtered at 18.0°C. Only the saturated solution was used to moisten the paper. The filtrate was caught in a clean, dry, 250.00mL beaker.

10.0mL of the saturated solution was pipetted into a 250.00mL Erlenmeyer flask. A few drops of phenolphthalein indicator was added using 0.02499*M* standard sodium hydroxide solution in a 25.00mL burette.

The titration values were recorded in Table 5.1.

Table 5.1. Table of recorded end-point titration values for KHT in 0.200M NaCl.

Trial	**End-point Value (mL)**
A	13.86
B	13.92

The average was determined to be 13.89mL, equal to 0.01389L.

Part 2. Solubility of KHT with Added K^+ as a Common Ion

The mixture assigned from Table 5.2 was B.

Table 5.2. Concentration of potassium ions added to mixtures A, B, & C to study the common ion

Mixture	**KCl concentrations *(M)***
A	0.0100
B	0.0300
C	0.0500

Repeat like in Part 1. The KHT mass for Part 2. was 2.0398g & the temperature was 18.1°C. Utilise NaCl in place of deionised water since Na completely dissociates, which allows for the Cl^- ion to make the KHT less soluble. The KHT was placed in a 250.0mL bottle & it was filled to the halfway mark with mixture B. The solution was vigorously shaken for two minutes before being filtered & titrated like in Part 1.

The titration values were recorded in Table 5.3.

Table 5.3. Table of recorded end-point titration values for KHT in Mixture B.

Trial	**End-point Value (mL)**
A	8.87
B	8.94

The average was determined to be 8.905mL, equal to 0.008905L.

Part 3. Molar Solubility & Ksp Values for Collective Class Results

The molar solubilities for the entire class were also collected for all four solutions analysed in the experiment. In *Appendix B* of the report, one can access the data collected from two properly formatted tables.

III. Results

Part 1. Solubility of KHT in 0.200*M* NaCl

The molar solubility of KHT was calculated using equation (5.4).

$$\text{molar solubility KHT} = \frac{(V_{NaOH})(M_{NaOH})(\frac{1molHT^{-}}{1molNaOH})}{V_{KHTsolution}} \tag{5.4}$$

$$\text{molar solubility KHT} = \frac{(0.01389L_{NaOH})(0.02499M_{NaOH})(\frac{1molHT^{-}}{1molNaOH})}{0.01000L_{KHTsolution}}$$

molar solubility KHT = $0.03471111M$

molar solubility KHT = $0.0347M$

$[HT^{-}]_{ave} = 0.0347M$

The equilibrium constant was calculated using equation (5.5).

$$K_{sp} = [K^{+}][HT^{-}] \tag{5.5}$$

$K_{sp} = ([HT^{-}]_{ave})^2$

$K_{sp} = (0.03471111)^2$

$K_{sp} = 0.0012048612M$

$K_{sp} = 0.00120$

$[K^{+}]$ is equal to $[HT^{-}]_{ave}$ because there is no other source for the potassium ion. Thus, the molar ratio states that the concentrations are equal. Therefore, the equation simplifies to the concentration of $[HT^{-}]_{ave}$ squared.

Part 2. Solubility of KHT with Added K^{+} as a Common Ion

The molar solubility of KHT was calculated using equation (5.4) as well.

$$\text{molar solubility KHT} = \frac{(0.008905L_{NaOH})(0.02499M_{NaOH})(\frac{1molHT^{-}}{1molNaOH})}{0.01000L_{KHTsolution}}$$

molar solubility KHT = $0.022253595M$

molar solubility KHT = $0.0223M$

$$[HT^-]_{ave} = 0.0223M$$

The molarity for K^+ was calculated using equation 5.6.

$$[K^+] = [KCL] + [HT^-]_{ave} \qquad (5.6)$$

$$[K^+] = 0.0300M \text{ KCL} + 0.022253595M \text{ HT}^-_{ave}$$

$$[K^+] = 0.05225359M$$

$$[K^+] = 0.0523M$$

Thus, K_{sp} was calculated using Eq. (5.7).

$$K_{sp} = [K^+] \times [HT^-]_{ave} \qquad (5.7)$$

$$K_{sp} = 0.05225359M \times 0.022253595M$$

$$K_{sp} = 0.0011628303$$

$$K_{sp} = 0.00116$$

The equations used were different to Part 1. since there are excess K+ ions due to the addition of KCl.

Part 3. Molar Solubility & *Ksp* Values for Collective Class Results

In Appendix B of the report, data for the molar solubilities can be accessed in the form of two tables (one for Part 1. & another for Part 2.) The K_{sp} values for each of the four KHT solutions were summarised in excel to create Table 5.4

Table 5.4. Table of average molar solubilities for Part 1. & Trials A, B, C, & their *Ksp*

Solution	**Average Molar Solubility *(M)***	**Ksp Value**
Part 1.	0.0343	1.18×10^{-3}
Mixture A.	0.0296	1.17×10^{-3}
Mixture B.	0.0221	1.15×10^{-3}
Mixture C.	0.0169	1.13×10^{-3}

To calculate K_{sp}, the following equation was used for Part 1;

$$K_{sp} = ([HT^{-}]_{ave})^2$$

To calculate K_{sp} for mixtures A, B, & C, the following equation was used;

$$K_{sp} = [K^{+}] \times [HT^{-}]_{ave}$$

IV. Error Analysis

The percentage error for my calculated K_{sp} value in the 0.0200*M* NaCl solution was determined using the following equation. To calculate it, the accepted K_{sp} value at 18°C was used, which is equal to 1.25×10^{-3}.

$$\% \text{ error} = \left|\frac{Experimental\ Value - Theoretical\ Value}{Theoretical\ Value}\right| \times 100\%$$

$$\% \text{ error} = \left|\frac{0.0012048612 - 0.00125}{0.00125}\right| \times 100\%$$

$$\% \text{ error} = 3.611104\%$$

$$\% \text{ error} = 3.61\%$$

Moreover, to calculate the standard deviations for K_{sp} & [HT $^-$] in 0.0200*M* NaCl & the three class mixtures, Excel was utilised. To do so, the function STDEV.S(data range) was employed, which uses the following equation;

$$\sigma = \sqrt{\frac{\sum(x_i - \mu)^2}{N}}$$

The data was collected in Table 5.5.

Table 5.5. Table of standard deviations calculated with Excel for Ksp & [HT $^-$] in Part 1. & Mixtures A, B, & C

Solution	Standard Deviation [HT $^-$]	Standard Deviation K_{sp}
Part 1.	0.00135	9.24×10^{-5}
A	0.00132	9.12×10^{-5}
B	0.000879	6.57×10^{-5}
C	0.000815	6.85×10^{-5}

Following the ANOVA calculations, that were also conducted in Excel, it was determined that the *F*-statistic = 0.784, *F*-critical = 2.72, & *p*-value = 0.5.

The K_{sp} values were not significantly different since it can be assumed that everyone measured roughly the same grams of salt (approximately 2.00g) & followed the titration techniques adequately. Thus, even though there is some variance, it is not significant & no anomalies were recorded.

V. Discussion

Based on the K_{sp} values given on the lab manual, the best supplement source would be Calcium lactate since its K_{sp} is equal to 5.8×10^{-3}, indicating high solubility. For a supplement, high solubility would be ideal for it to enter your blood stream.

Based on the class results, it was evident that the K^+ ions caused the KHT to become less soluble since Mixture C, which had the greatest KCl concentration, had the smallest average molar solubility (1.69×10^{-2}). On the other hand, Mixture A, which had the smallest KCl concentration, proved that less K^+ ions makes the solution more soluble since its average molar solubility was much greater - 2.96×10^{-2}. The effect these ions had on the K_{sp} was less significant, however, the greater concentration of potassium ions, the smaller the K_{sp}.

According to Le Chatelier's principle, if a reaction at equilibrium increases in temperature, the reaction will shift to the left to balance out the extra temperature. Because of this, if there was an increase in temperature, the KHT solubility would increase as well to help balance out the reaction. However, the K_{sp} would remain nearly unchanged.

If the all of the class K_{sp} values were rounded to two significant figures, they would all have nearly the same K_{sp} which would be either 1.1×10^{-3} or 1.2×10^{-3}. They are relatively constant after the common ion is added, since as Le Chatelier explained, only the equilibrium position would be affected, not the K_{sp} itself.

My [HT $^-$]$_{ave}$ in NaCl was equal to 0.0347*M,* which did fall within one standard deviation (1.35×10^{-3}) to the class average which was 0.0343 *M.* Additionally, my mixture was mixture B & my [HT $^-$]$_{ave}$ was equal to 0.0223*M,* which did not fall within one standard deviation (8.79×10^{-4}) to my group's average which was 0.0221*M.* The limit would be 0.022999*M,* which I just barely went over by getting 0.0223*M.*

VI. Conclusion

The molar solubility at 18.0°C for Part 1. was equal to 0.0347*M,* its respective K_{sp} value was equal to 1.20×10^{-3}. For Mixture B it was calculated at 18.1°C & the molar solubility was 0.0223*M* & the K_{sp} value was equal to 1.16×10^{-3}. The percentage error for K_{sp} was determined to be 3.61%. The class values can be summarised in Table 5.6.

Table 5.6. Summarised of class results, with their respective standard deviations

Solution	**KHT**	***Ksp***
Part 1.	0.0343 ± 0.00135	$1.18 \times 10^{-3} \pm 9.24 \times 10^{-5}$
Mixture A.	0.0296 ± 0.00132	$1.17 \times 10^{-3} \pm 9.12 \times 10^{-5}$
Mixture B.	0.0221 ± 0.000879	$1.15 \times 10^{-3} \pm 6.57 \times 10^{-5}$
Mixture C.	0.0169 ± 0.000815	$1.13 \times 10^{-3} \pm 6.85 \times 10^{-5}$

The calculated values determined that the *F*-statistic = 0.784, *F*-critical = 2.72, & *p*-value = 0.5. With these we can conclude that the K_{sp} values were not significantly different & were actually, relatively similar.

VII. References

1. 1. R.C. Bell & D.M Brinkel, Chemistry 113: Experimental Chemistry II Laboratory Manual, Page 88-97

2. Safety Data Sheet. (n.d.). Chemical info for Potassium thiosulfate. SDS. Retrieved April 10, 2025, from https://chemicalsafety.com/sds1/sdsviewer.php?id=33624763&name=Potassium%20thiosulfate
3. Safety Data Sheet. (n.d.). Chemical info for Sodium chloride. SDS. Retrieved April 10, 2025, from https://chemicalsafety.com/sds1/sdsviewer.php?id=33196158&name=Sodium%20chloride
4. Safety Data Sheet. (n.d.). Chemical info for Sodium hydroxide. SDS. Retrieved April 10, 2025, from https://chemicalsafety.com/sds1/sdsviewer.php?id=33168306&name=Sodium%20hydroxide

Appendix A. Safety Hazards

POTASSIUM THIOSULFATE [2]

by AK Scientific, Inc.

Warning

Hazard statements

Causes serious eye irritation

Causes skin irritation

May cause respiratory irritation

Precautions

Avoid breathing dust/fume/gas/mist/vapours/spray

Wash ... thoroughly after handling

Use only outdoors or with adequate ventilation.

Wear protective gloves/protective clothing/eye protection/face protection

IF ON SKIN: Wash with plenty of water.

IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing

IF IN EYES: Rinse cautiously with water for several minutes, Remove contact lenses, if present and easy to do. Continue rinsing

Call a POISON CENTER or doctor/physician if you feel unwell

Specific treatment (see ... on this label)

If skin irritation occurs: Get medical advice/attention

If eye irritation persists: Get medical advice/attention

Take off contaminated clothing

Store in a well-ventilated place., Keep container tightly closed

Store locked up

Dispose of contents/container to ...

Hazard category

Serious eye damage/eye irritation (3.3), Skin corrosion/irritation (3.2), Specific target organ toxicity - single exposure (3.8)

SODIUM CHLORIDE [3]

by AK Scientific, Inc.

Warning

Hazard statements

Causes serious eye irritation
Causes skin irritation
May cause respiratory irritation

Precautions

Avoid breathing dust/fume/gas/mist/vapours/spray
Wash ... thoroughly after handling
Use only outdoors or with adequate ventilation.
Wear protective gloves/protective clothing/eye protection/face protection
IF ON SKIN: Wash with plenty of water.
IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing
IF IN EYES: Rinse cautiously with water for several minutes, Remove contact lenses, if present and easy to do. Continue rinsing
Call a POISON CENTER or doctor/physician if you feel unwell

Specific treatment (see ... on this label)

If skin irritation occurs: Get medical advice/attention

If eye irritation persists: Get medical advice/attention

Take off contaminated clothing

Store in a well-ventilated place., Keep container tightly closed

Store locked up

Dispose of contents/container to ...

Hazard category

Serious eye damage/eye irritation (3.3), Skin corrosion/irritation (3.2), Specific target organ toxicity - single exposure (3.8)

SODIUM HYDROXIDE [4]

by AK Scientific, Inc.

Warning

Hazard statements

Causes serious eye irritation

Causes skin irritation

May be corrosive to metals

Precautions

IF ON SKIN: Wash with plenty of water.

IF IN EYES: Rinse cautiously with water for several minutes, Remove contact lenses, if present and easy to do. Continue rinsing

Hazard category

Corrosive to metals (2.16), Serious eye damage/eye irritation (3.3), Skin corrosion/irritation (3.2)

Appendix B. Lab Notebook Pages