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EXPERIMENT 12  
A SOLUBILITY PRODUCT CONSTANT

**PURPOSE:**

1. To determine experimentally the molar solubility of potassium acid tartrate in water and in a solution of potassium nitrate.
2. To examine the effect of a common ion on the solubility of slightly soluble salts.

**PRINCIPLES:**

When a large amount of a slightly soluble ionic compound,  $[M^+][A^-]$ , is mixed with water, the compound partially dissolves in water and a saturated solution is formed. Some of the solid remains undissolved.

An equilibrium occurs between the undissolved solid and the ions in the solution.



The equilibrium **constant** for the solubility process is called the Solubility Product Constant ( $K_{sp}$ )

$$K_{sp} = [M^+][A^-]$$

The  $K_{sp}$  for a slightly soluble salt is determined by measuring the concentrations of the  $M^+$  and  $A^-$  ions in a saturated solution. In this experiment, we can measure the concentration of the anion because it is a weak acid which can be titrated with a strong base.

Tartaric acid ( $H_2C_4H_4O_6$ , or  $H_2Tar$ ) is a weak diprotic acid. If enough  $KOH$  is added to a solution of tartaric acid to neutralize only **half** the acidic hydrogens, the salt potassium acid tartrate ( $KHC_4H_4O_6$  or  $KHTar$ ) is obtained as a slightly soluble salt.

When  $KHTar$  is dissolved in water, the following equilibrium exists:



$HTar^-(aq)$  is a weak acid and, as such, it can be titrated with a strong base, like sodium hydroxide, and this neutralization reaction proceeds to completion:



Thus we can determine experimentally the concentration of a  $HTar^-$  solution by titrating it with a sodium hydroxide solution of known concentration.

In this experiment, you will measure the Molar Solubility of  $KHTar$  in two solvent systems: pure water and 0.10 M  $KNO_3$ . The Molar Solubility of  $KHTar$  will be determined by titration of the  $HTar^-$  ion with standardized  $NaOH$ .

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The  $K_{sp}$  of KHTar in these solvents is given by:

$$K_{sp} = [K^+] [HTar^-]$$

In pure water the only source of potassium and acid tartrate ions is the dissolved KHTar, which, in view of the negligible amount of dissociation of  $HTar^-$  leads to the following relation:

$$[K^+] = [HTar^-] = \text{Molar Solubility (Commonly abbreviated "S")}$$

The concentration of the  $HTar^-$  is found by knowing how many moles of  $HTar^-$  are contained in a known volume of solution,  $V_s$ .

Since  $HTar^-$  reacts with the sodium hydroxide in a 1:1 mole ratio:



the moles of  $HTar^-$  are equal to the moles of NaOH used to reach the endpoint .

$$\text{moles } HTar^- = \text{moles NaOH} = (M_{NaOH}) (\text{Volume of NaOH solution})$$

$[HTar^-] = \frac{(M_{NaOH}) (\text{Volume of NaOH solution})}{\text{Volume of KHTar solution}}$
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In the 0.10 M  $KNO_3$  solution, the concentration of  $HTar^-$  is found in the same fashion. However, there are now two sources of potassium ions: from the dissolved KHTar and from the strong electrolyte,  $KNO_3$ , which in an aqueous solution is totally dissociated into potassium and nitrate ions. .

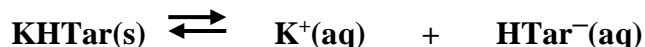
The concentration of potassium ions is given by:

$$[K^+] = [KNO_3] + [KHTar^-]$$

It follows that:

$$K_{sp} = \left( [KNO_3] + [KHTar^-] \right) [HTar^-]$$

Recall that the following equilibrium exists in solution:



The addition of  $K^+$  ions from  $KNO_3$  (potassium nitrate) will shift the solubility equilibrium to the left, thus lowering the solubility of KHTar.

This lowering of solubility by addition of a salt containing a common ion is called the **common ion effect**.

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**PROCEDURE:****I. Preparation of the saturated solutions**

The workload will be divided in the following manner:

**Team member 1:**

**Will prepare a saturated solution of potassium acid tartrate dissolved in deionized water as indicated below:**

1	Weigh out about 2 g of Potassium Acid Tartrate on a centigram or milligram balance into a 250 mL Erlenmeyer flask, labeled <b>Aqueous Solution</b> .
2	Add about 150 mL of <b>deionized water</b> to the flask.
3	Agitate the flask by swirling it vigorously for about 15 minutes. For more efficient mixing you may want to place a magnet in the flask and place the flask on a stirring plate. Do not expect all of the solid to dissolve; the solution is a saturated solution and the mass of potassium acid tartrate (2 g) added to prepare the solution is purposely more than can dissolve in 150 mL of deionized water.
4	At the end of this time, let the solid settle out and measure the temperature of the supernatant (the clear solution above the undissolved solid)
5	Filter the supernatant liquid from the Erlenmeyer flask and collect the clear, colorless filtrate solution into a 200 mL, 250 mL or 400 mL beaker, labeled <b>Aqueous Solution</b> . You may discard the undissolved solid.
6	Recover the stirring magnet from the Erlenmeyer flask by adding water to the flask and pouring the contents of the flask through a funnel, in order to catch the magnet.

**Team member # 2:**

**Will prepare a saturated solution of potassium acid tartrate dissolved in 0.10 M KNO<sub>3</sub> as indicated below :**

1	Weigh out about 2 g of Potassium Acid Tartrate on a centigram or milligram balance into a 250 mL Erlenmeyer flask, labeled <b>0.10 M KNO<sub>3</sub></b>
2	Add about 150 mL of <b>0.10 M KNO<sub>3</sub></b> to the flask.
3	Agitate the flask by swirling it vigorously for about 15 minutes. For more efficient mixing you may want to place a magnet in the flask and place the flask on a stirring plate. Do not expect all of the solid to dissolve; the solution is a saturated solution and the mass of potassium acid tartrate (2 g) added to prepare the solution is purposely more than can dissolve in 150 mL of <b>0.10 M KNO<sub>3</sub></b> .
4	At the end of this time, let the solid settle out and measure the temperature of the supernatant (the clear solution above the undissolved solid)
5	Filter the supernatant liquid from the Erlenmeyer flask and collect the clear, colorless filtrate solution into a 200 mL, 250 mL or 400 mL beaker, labeled <b>0.10 M KNO<sub>3</sub></b> . You may discard the undissolved solid.
6	Recover the stirring magnet from the Erlenmeyer flask by adding water to the flask and pouring the contents of the flask through a funnel, in order to catch the magnet.

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## II. Titrations

In order to obtain duplicate data, each team members will perform two titrations, as indicated below:

### First Titration

**The solution of Potassium Hydrogen Tartrate (KHTar) dissolved in Deionized Water will be titrated with a standardized solution of NaOH, approximately 0.10 M.**

1. Rinse and fill your buret with the standardized NaOH solution.
2. Rinse your clean 100 mL or 50 mL graduated cylinder with a few mL of the aqueous solution of KHTar (KHTar dissolved in Deionized Water).
3. Carefully measure out 50.0 mL portions of this solution (KHTar dissolved in Deionized Water) into a labeled 250 mL Erlenmeyer flasks.
4. Add two drops of phenolphthalein indicator solution to each flask.
5. Titrate the solution to the “pale pink end-point”, recording the volume of NaOH used for the titration.

### Second Titration:

**The solution of Potassium Hydrogen Tartrate (KHTar) dissolved in 0.10 M KNO<sub>3</sub> will be titrated with a standardized solution of NaOH, approximately 0.10 M.**

1. Rinse and fill your buret with the standardized NaOH solution.
2. Rinse your clean 100 mL or 50 mL graduated cylinder with a few mL of the solution of KHTar dissolved in 0.10 M KNO<sub>3</sub>.
3. Carefully measure out 50.0 mL portions of this solution (KHTar dissolved in 0.10 M KNO<sub>3</sub>) into a labeled 250 mL Erlenmeyer flasks.
4. Add two drops of phenolphthalein indicator solution to each flask.
5. Titrate the solution to the “pale pink endpoint”, recording the volume of NaOH used for the two titrations.

## III. Calculations

1. Combine the experimental data obtained by both team members and proceed with the calculations, as outlined in the Report Form.
2. Use the exact molarity of the standardized solution of NaOH (to the nearest 0.0001 M) as indicated on the bottle.

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NAME: \_\_\_\_\_

Date; \_\_\_\_\_

**REPORT FORM****Part I: Molar Solubility of Potassium Acid Tartrate (KHTar) in Deionized Water**

Temperature of Solution: \_\_\_\_\_ °C

**Titrations**

	<u>Team Member 1</u>	<u>Team Member 2</u>
NAMES:	_____	_____
Molarity of Standardized NaOH solution:	_____ M	_____ M
Final buret reading (mL):	_____	_____
Initial buret reading (mL):	_____	_____
Volume of titrant (mL):	_____	_____
Moles of NaOH used:	_____	_____
Moles of KHTar used to neutralize the above number of moles of NaOH:	_____	_____
Volume of saturated solution of KHTar (L)	_____	_____
Molarity of saturated solution of KHTar (M) dissolved in water	_____	_____
<b>Molar Solubility ("S") in water</b>	_____	_____
Molar Solubility ("S") of KHTar (M) in water		
<b>Average</b> (Experimental):	_____ M	

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**Calculate  $K_{sp}$  of  $KHTar$  in water from your experimental data**

1. Write the Solubility Equilibrium Expression for  **$KHTar$** .
  
2. Write the Solubility Product ( $K_{sp}$ ) expression for  **$KHTar$**
  
3. Calculate  $K_{sp}$  for  $KHTar$  in water, based on the experimentally determined Molar Solubility (“S”) of  $KHTar$

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Part II: Molar Solubility of Potassium Acid Tartrate (KHTar) in 0.10 M KNO<sub>3</sub>

Temperature of Solution: \_\_\_\_\_ °C

**Titrations**Team Member 1Team Member 2

NAMES: \_\_\_\_\_

Molarity of Standardized NaOH solution: \_\_\_\_\_ M

Final buret reading (mL): \_\_\_\_\_

Initial buret reading (mL): \_\_\_\_\_

Volume of titrant (mL): \_\_\_\_\_

Moles of NaOH used: \_\_\_\_\_

Moles of KHTar used to  
neutralize the above number of  
moles of NaOH: \_\_\_\_\_Volume of saturated solution  
of KHTar(L) \_\_\_\_\_Molarity of saturated solution  
of KHTar (M) dissolved in 0.10 KNO<sub>3</sub>  
**Molar Solubility ("S") in 0.10 KNO<sub>3</sub>** \_\_\_\_\_Molar Solubility ("S") of  
KHTar (M) in 0.10 KNO<sub>3</sub>  
**Average (Experimental):** \_\_\_\_\_ M

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Calculate the theoretical Molar solubility of KHTar in 0.10 M  $\text{KNO}_3$  by using the  $K_{sp}$  of KHTar in water determined in Part I (see page 6)

Solubility Expression:

**CONCENTRATIONS:**

Initial:

Change:

Equilibrium:

Show calculations below:

**Calculation of Percent Error****Molar solubility of KHTar in 0.10 M  $\text{KNO}_3$** 

(calculated); see above

\_\_\_\_\_ M

**Molar solubility of KHTar in 0.10 M  $\text{KNO}_3$** 

(experimental); see page 7

\_\_\_\_\_ M

**Percent Error:**

Show calculations below:

\_\_\_\_\_ %



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**CONCLUSIONS:**

1. What is the experimentally determined **Molar solubility of KHTar in water?**

(Part I)

\_\_\_\_\_ M

2. What is the experimentally determined **Molar solubility of KHTar in 0.10M KNO<sub>3</sub>?**

(Part II)

\_\_\_\_\_ M

3. Explain why the two Molar Solubilities listed in 1(a) and 2(b) above are quite different.

**Part III: EXTENDING THE CONCEPTS:**

The Solubility Product Constant of AgBr is  $K_{sp} = 5.0 \times 10^{-13}$

1. Calculate the molar solubility of Ag Br in water.

Please show clearly all relevant equations and calculations.

