Solubility of a Salt in Water at Various Temperatures

Caution Potassium chlorate is a skin and eye irritant.

Purpose

Most ionic compounds are considered by chemists to be salts and many of these are water soluble. In this lab, you will determine the solubility, that is, how much of a salt can dissolve in water, of $KClO_3$ (potassium chlorate). In particular, we will be determining solubility at different temperatures.

Introduction

Intermolecular forces are those forces that hold molecules together as solids and liquids. The cations and anions of an ionic compound are held together in the solid state by complexing with many ions of the opposite charge. Hydrogen bonding gives water many of its extraordinary properties and salts dissolve in water because their charges line up with the partial charges on water. Water molecules surround each ion, resulting in a three-dimensional "solvent cage" around the charged particle (Figure 1).

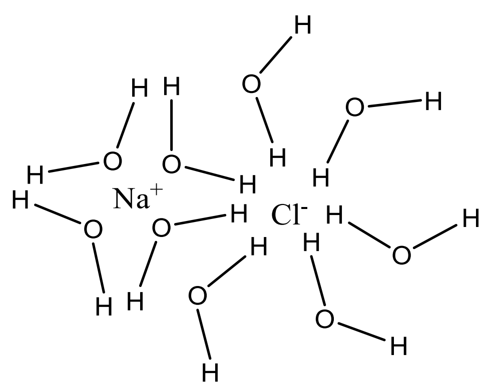

Figure 1: Depiction of solvent cage breaking apart the ionic bond in sodium chloride.

To understand this lab, you will need to review a few definitions regarding solubility:

- Solution—when one substance (not necessarily a solid) is dissolved in another substance (not necessarily a liquid), a solution forms. Salt water, for example, is a solution of solid sodium chloride in liquid water. Rubbing alcohol is also a solution, where water is dissolved in the liquid isopropyl alcohol.
- Solute—the material that is dissolved in a solution. This is the chemical that is in lesser quantity. In salt water and rubbing alcohol, the salt and water are the solutes, respectively.
- Solvent—the liquid that dissolves the solute to form a solution. This is the chemical that is in abundance in a solution. In salt water and rubbing alcohol, the solvents are water and isopropyl alcohol, respectively.

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- Unsaturated solutions—in an unsaturated solution, all particles of the solute are dissolved in the solvent. In fact, there is room in the solvent to dissolve more of the solute. There will be no visible solid salt in an unsaturated solution.
- Saturated solutions—in a saturated solution, as much salt as possible will be in solution. That is, the solution is saturated with as much solute as possible. To saturate the solution, it often needs to be heated. In a saturated solution, you will see crystals of the solid salt at the bottom of the solution.
- Supersaturated solutions—A supersaturated solution has more salt dissolved in it than theoretically possible. The formation of crystals is not always easy for the salt and requires certain conditions. When a saturated solution is really hot and starts to cool down, the crystals may not form immediately. This leads to more solute being dissolved in the solvent than is stable at that temperature. It doesn't take much to get crystals to form in a supersaturated solution. An example is in hot packs, where you have to bend the metal piece to get the liquid to turn solid and it turns hot. This is an example of a supersaturated sodium acetate solution that crystallizes and releases heat in the process. All it takes is a little snap of the metal piece to initiate the process.

Each salt acts differently when dissolved in water, and this is due to the physical properties of the ions in each salt. Polyatomic ions, ions that are made of multiple atoms, will act much differently than a monatomic ion like chloride. We can ask the question, what is the solubility of solute A in solvent B? The answer to this question is usually answered in grams of A per 100 g of water.

There is also an important factor in solubility that we have not yet mentioned, temperature. Imagine trying to dissolve sugar in your cold iced tea compared to dissolving sugar in hot tea. The hot tea dissolves sugar much easier. This is also the case with salts. Hot water dissolves salt *faster* than cold water but does not necessarily dissolve *more* salt than cold water. While many salts do have higher solubilities in hot water compared to cold water, some salts actually have less solubility in hotter water. We can report the solubility of a chemical at various temperatures. For example, the solubility of KBr in water at 25 ^{o}C is 64 g/100 g water. At 100 ^{o}C, the solubility increases to about 100 g KBr/100 g water. In this lab, you will be making a solution of potassium chlorate and heating it until it dissolves. You can watch the test tube as the temperature falls to determine the temperature of crystallization; that is, the temperature that the salt loses its solubility. You will be adding water to the test tube over several trials, making more dilute solutions, and determining the solubility for those as well. From there, you can graph the results to predict potassium chlorate solubility at different temperatures.

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Equipment

Large test tube and clamp	split rubber stopper	110 ^{o}C thermometer
10-mL graduated cylinder	ring stand	Bunsen burner
Wire stirrer	distilled water	4.5-5.0 g potassium chlorate

Procedure

I. Assemble the apparatus as shown in Figure 2. You will need to make sure the wire stirrer is around the thermometer so you can easily stir the solution as it heats. Use a 20 cm test tube with the stopper, stirring wire, and thermometer as your apparatus, and attach it to a ring stand with a clamp. Add a Bunsen burner underneath. You may want to keep out a beaker to rest your test tube in while you work.

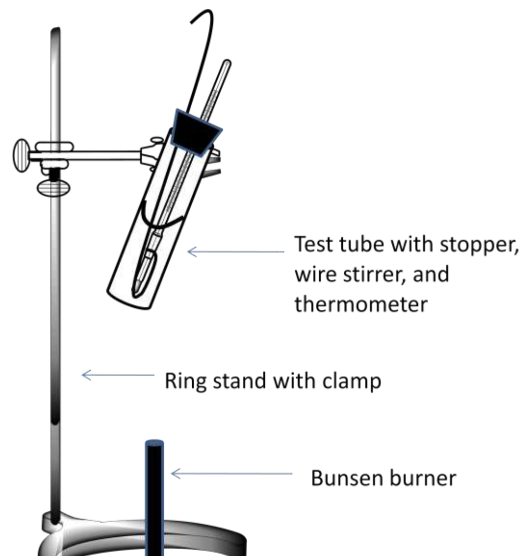

Figure 2: Scheme of apparatus

II. Weigh 4.5-5.0 grams of salt on a balance and record the exact mass on the data sheet.

III. Using a graduated cylinder, measure out about 10 mL of water and add it to the salt in the apparatus. Record the *mass* of water on your data sheet (remember that 1 mL of water has a mass of 1 g).

IV. Clamp the apparatus to the ring stand and heat it, stirring it continuously as it heats by moving the stirrer up and down until the solid salt dissolves. You will want to use a cool flame—don't use an interior blue cone to heat because it will crack your test tube.* Turn off the burner and stir continuously and vigorously as the apparatus cools down by moving the stir wire up and down the test tube. Record the exact temperature (in ^{o}C) when you see crystals of salt forming.

V. Cool down the test tube until it is warm to the touch. You can put it under the watertap to speed this up. Measure about 4 mL of water and add to the previous 10 mL in the test tube. DON'T dump out what is already in the test tube. You are simply adding 4 mL of water to what is already there. Record the mass of how much water you add. Repeat step IV and record your data.

VI. Add 4 mL of water to the previous 14 mL. Repeat step IV and record the data.

VII. Add 4 mL of water to the previous 18 mL. Repeat step IV and record the data.

VIII. Add 4 mL of water to the previous 22 mL. Repeat step IV and record the data.

IX. Pour your salt water solution to the waste container.

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*If you crack a test tube, you will need to use a new test tube, measuring a new quantity of salt. Indicate on your data sheet when the test tube cracks and record the new quantity of salt. You will need to start where you left off with the volume of water, so add enough water to make up the amount in your tube when it cracked.

Calculations

Fill in the prepared table on data sheet 2. The mass of the salt does not change, only the mass of the water. Remember to use the total amount of water in the test tube at any given measurement, not just the water you added for that particular step.

To calculate the solubility, you will need to use the formula:

$$\frac{\textit{mass of salt (g)}}{\textit{mass water (g)}} = \frac{x}{\textit{100 g water}}$$

Solving for *x*, the solubility of salt, we get the formula:

$$x = \frac{\textit{mass of salt (g) x 100 g water}}{\textit{mass of water (g)}}$$

where *x* is the solubility of salt in units of g/100 g water.

Prepare a graph of solubility (grams of salt dissolved in 100 g water) on the y axis vs. temperature of crystallization in Celsius on the x-axis. Use a smooth line to connect the points in the best possible fit (it may not necessarily be a straight line). You will want to extend the line past the points in both directions to answer the post-lab questions.

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Data Sheet 1

Name:________________________________ **Partner:** __________________________________

1. Mass of salt __________________g
2. Mass of water __________________g
3. Temperature of crystallization for IV __________________^oC

4. Mass of water added in V __________________g
5. Total mass of water in test tube __________________g
6. Temperature of crystallization for V __________________^oC

7. Mass of water added in VI __________________g
8. Total mass of water in test tube __________________g
9. Temperature of crystallization for VI __________________^oC

10. Mass of water added in VII __________________g
11. Total mass of water in test tube __________________g
12. Temperature of crystallization for VII __________________^oC

13. Mass of water added in VIII __________________g
14. Total mass of water in test tube __________________g
15. Temperature of crystallization for VIII __________________^oC

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Data Sheet 2

Complete the following data table for each section on Data Sheet 1. Use the formula on page 4 to determine the salt concentration and show a sample calculation below. Use this table and a computer spreadsheet program to construct your graph. Connect points with a best-fit line and extend the line beyond your data. Label your axes and include a title for your graph.

Section	**Water mass (g)**	**Salt concentration ($g\ KClO_3$ / 100 $g\ H_2O$)**	**Crystallization temperature (^oC)**
IV			
V			
VI			
VII			
VIII			

Sample calculation of salt concentration:

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Post-lab Questions

Name:________________________________ Partner(s): ____________________________

1. Predict the solubility of your salt at the following temperatures (use correct units):

   a. 70 ^{o}C ____________________________________

   b. 50 ^{o}C ____________________________________

   c. 30 ^{o}C ____________________________________

2. How would your graph change if you added 1 mL too much water in one step, then added 1 mL less the next step to compensate for it? How would this affect your solubility measurements from the table? This requires a bit of thought so be careful!!!

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3. How could you have gotten better results for this lab?

   ____

   ____

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Pre-Lab Assignment

Name:____

1. Many liquids you use are actually solutions made of a solute dissolved in a solvent. What is an example of a solution in your kitchen? _______________________________

2. What is an example of a solution in your bathroom? _____________________________

3. Sodium bicarbonate, or baking soda, is a common salt found in your home. Sodium bicarbonate is only partially soluble in water at room temperature. How could you increase the solubility of sodium bicarbonate in water?

   ____

   ____

4. How could you decrease the solubility of baking soda?

   ____

   ____

5. What is the solute in this lab? ____

6. What is the solvent used in this lab? ____

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7. Practice plotting data points: In this lab you will be plotting points to get a graph and answer questions regarding that graph. There are example data plots below for the solubility experiments of lead nitrate. Plot these points and answer the following questions.

Temperature (^oC) x-axis	Solubility ($g\ Pb(NO_3)_2/100\ g$ water) y-axis
92.1	115
70.1	91.2
49.6	78.6
31.2	61.4

Draw a line between the points and beyond in both directions past the data points. Use this line to answer the following questions.

a. What would the solubility be at 35 ^oC of lead nitrate? ______________________________

b. What would the solubility be at 25 ^oC of lead nitrate? ______________________________

c. What temperature would be necessary to create a solution with solubility of

65.0 g/100 mL? ___________________