

## Experiment 4

### Solubility of a Salt

#### OUTCOMES

After completing this experiment, the student should be able to:

- measure the temperature at which a solution becomes saturated.
- construct a solubility curve for a solute.
- determine the concentration of an unknown solution from its saturation temperature.

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#### DISCUSSION

**Solubility** is defined as the maximum amount of solute that will dissolve in a given amount of solvent at a specified temperature. Typically, solubilities are recorded as grams of solute per 100 g of solvent. The solubility of a substance can be affected by a variety of factors including the identity of the solute and solvent, the temperature of the solution, and by the pressure exerted on the solution when the solute is a gas.

Substances tend to be more soluble when the intermolecular forces holding them together are similar to the intermolecular forces present in the solvent. This trend leads to the axiom "like dissolves like." In general, ionic compounds are soluble in water due to the attraction between the charges of the ions and the dipole moment of the water but are insoluble in nonpolar solvents which do not have the permanent dipole moment.

For many liquid and solid solutes, increasing the temperature of the solution increases the solubility of the solute, that is, more of the solute dissolves in the same amount of solvent. This is because the increased temperature leads to greater motion within the solute which makes it easier for the intermolecular forces holding it together to be overcome. With gaseous solutes, the opposite is true. Increasing the temperature and motion of the solute increases its ability to escape from the solvent, lowering its solubility. Instead, the solubility of a gas can be increased by raising the pressure exerted on the solution, essentially "pushing" more of the gaseous solute into the solution.

Regardless of the identity of the solute and the temperature of the solution, it is not possible to dissolve an unlimited amount of solute into a given solution. When the maximum amount of solute has been dissolved at a particular temperature, the solution is said to be **saturated** and the addition of any more solute will simply precipitate out of the solution. The behavior of a particular solute can be represented graphically with a **solubility curve** which plots the solubility of the solute (*y*-axis) vs. temperature (*x*-axis). When a solution is at a temperature and concentration that fall on the curve, the solution is *saturated*. If the solution falls below

the curve, it has less than the maximum amount of solute required for saturation, so the solution is considered *unsaturated*. If the solution is above the curve, it is classified as *supersaturated* because it has more solute than required for saturation in the solution.

In this experiment, you will construct a solubility curve for  $\text{KNO}_3$ . This will be done by combining different amounts of the salt in similar amounts of water and heating the solutions until all of the solute completely dissolves. Once the solid is dissolved, the solution will be constantly stirred and allowed to cool until the temperature is low enough for the solution to become saturated. This point is indicated by the formation of small crystals that look like snowflakes within the solution system. Once it is completed, the solubility curve will be used to determine the concentration of a solution with an unknown  $\text{KNO}_3$  concentration.

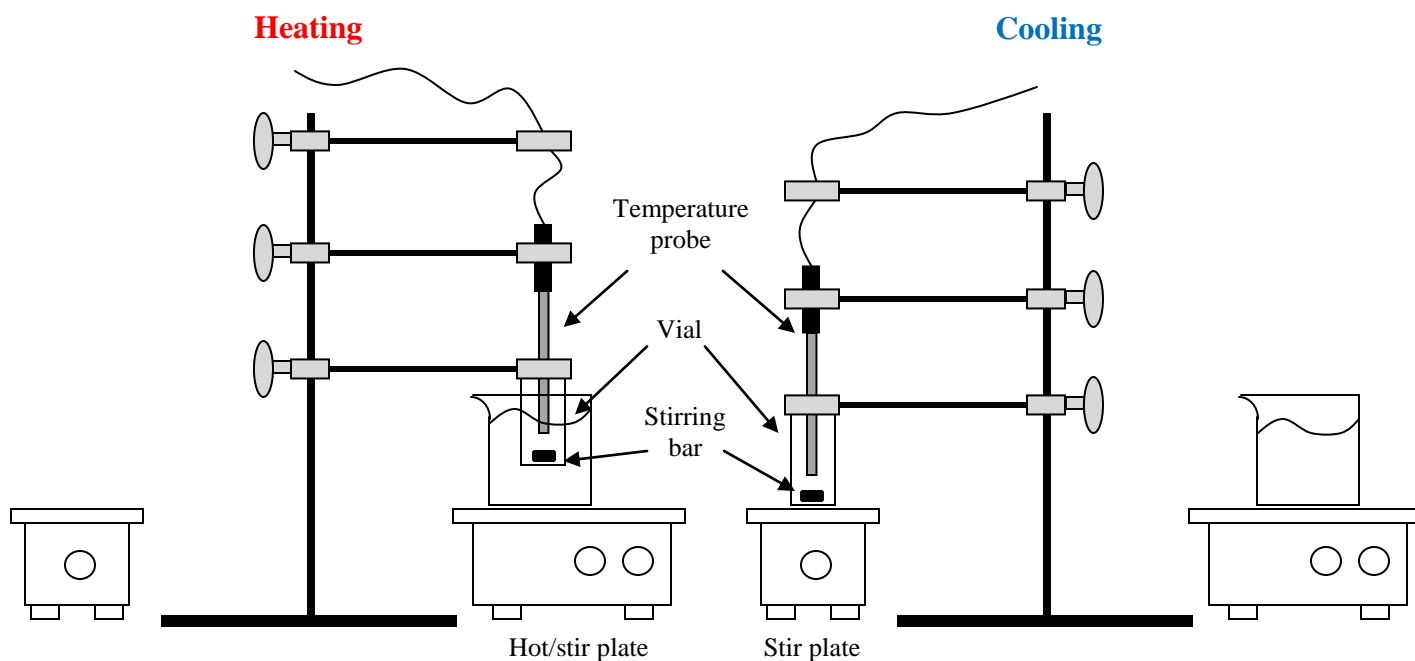
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## PROCEDURE

⚠ **Wear safety glasses or goggles at all times for this experiment.**

⚠ **Never pipet by mouth.**

1. Construct the apparatus shown in Figure 1. Use a 50- or 100-mL beaker to make the hot water bath for the heating portion of the experiment. Note that initially, heating and stirring are accomplished using the hot/stir plate. As the solution is cooled, a second stir plate is used to stir the mixture.



**Figure 1.** Experimental apparatus for heating and cooling samples.

**⚠ Position all wires away from the hot plate! Always be watchful of the wires whenever you reposition the apparatus.**

2. Obtain six vials from the lab instructor and label them appropriately. Mass each vial with the cap on and record the masses. On a piece of weighing paper, measure out the amount of  $\text{KNO}_3$  given in the table below. Transfer the solid to its vial and re-mass each vial to determine the amount of solid actually transferred to the vial. Repeat this procedure for all six vials.

Vial #	Approximate $\text{KNO}_3$ mass (g)
1	~3.0 g
2	~2.5 g
3	~2.0 g
4	~1.5 g
5	~1.0 g
6	~0.5 g

3. Into each vial, pipet 2.00 mL of deionized water. Re-mass each vial to determine the mass of water actually transferred to the vial.
4. Connect a stainless steel temperature probe to the *LabPro* interface and open the Vernier *LoggerPro* application. If a digital meter for the temperature does not appear in the bottom left corner, go to the "Insert" menu and select a digital meter. There is no need to calibrate the temperature probe if it is a stainless steel probe.
5. Remove the cap from vial #1 and insert a small magnetic stir bar. Use clamps to support the vial in the hot water bath. Note that the bottom of the vial must be close to the bottom of the water bath for the magnetic stirrer to work. While the temperature probe does not have to be in the solution at this point, it should still be close to the surface of the solution so that its temperature is close to that of the  $\text{KNO}_3$  solution. Make sure that the temperature probe is clean and dry at the start of the trial.
6. Continue heating and stirring the solution until all of the solid has dissolved. Do not leave the vial in the water bath any longer than what is required to completely dissolve the solid.
7. When the  $\text{KNO}_3$  has dissolved, move the apparatus to a cold stir plate and continue stirring. At this point, the temperature probe should be fully inserted into the solution. Allow the vial to cool slowly. It will be necessary to construct a cold water bath in a small beaker to accelerate the process in some cases. Don't cool too quickly or you may miss the appearance of the crystals.

- At some point, crystals will form and gradually build in intensity as the solution cools (snow storm). Record the temperature on the digital meter at the instant crystals form. If the appearance of crystals is very sudden, supercooling of the solution may have occurred and it will be necessary to repeat the trial. You may reheat the apparatus and repeat the cooling process, always stirring, as often as necessary to obtain a good, reproducible temperature measurement as long as you do not remove and clean either the temperature probe or the stir bar.
- Once you are satisfied with the temperature measurement, remove and clean the temperature probe and stir bar.
- Repeat steps 5 to 9 with each of the numbered vials.
- Obtain an unknown  $\text{KNO}_3$  solution from the instructor and record the unknown number. Add the stir bar to the vial and heat the solution until the solid completely dissolves. Cool the solution and record the temperature when crystals form. Repeat as necessary to obtain a reproducible temperature measurement.

**⚠ *Dispose of all chemicals in the proper waste container.***

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## DATA ANALYSIS

- Use Microsoft *Excel* to construct a data table containing columns labeled with vial number, temperature ( $^{\circ}\text{C}$ ), mass of  $\text{KNO}_3$ , mass of water, and solubility ( $\text{g}_{\text{salt}}/100 \text{ g}_{\text{solvent}}$ ) for all six trials. Include a separate entry for the unknown solution's identification number, characteristic temperature, and concentration.
- Construct a solubility graph using the temperature and solubility information from the first six trials. Use the scatter plot option, but do NOT connect the dots.
- Perform a linear trendline analysis on the data. Try a second order polynomial trendline analysis. Note and record the equation and R-squared ( $R^2$ ) value for each trendline. The equation that best fits the data will have an R-squared value closest to 1.
- Calculate the concentration of your unknown solution using the equation for the trendline that best fits your data.

## POSTLAB ACTIVITY

You will be turning in a worksheet for this experiment. It will be completed either individually or in pairs, according to your instructor's directions. The tables and graphs that you generated in the data analysis will be incorporated into the worksheet.

Follow your instructor's directions for submitting the worksheet. If you are submitting electronically, please use the following convention for naming your worksheet: *Lastname1 Lastname2 Solubility*. If you are emailing the worksheet, use a subject line of *Chem 1062: Solubility Lab*.