1. The Solubility of a Salt

Objective

In this experiment, you will determine the solubility of a given salt at various temperatures. Also you will prepare the solubility curve for your salt.

Introduction

The term **solubility** in chemistry has both general and specific meanings. In everyday situations, we might say that a salt is *soluble,* meaning that experimentally, we were able to dissolve a sample of the salt in a particular solvent.

In a specific sense, however, the *solubility* of a salt refers to a definite numerical quantity. Typically, the solubility of a substance is indicated as the *number of grams of the substance that will dissolve in 100 g of the solvent.* More often than not the solvent is water. In that case the solubility could also be indicated as the number of grams of solute that dissolve in 100 mL (the density of water is near to 1.00 g/mL under ordinary conditions).

Since solubility refers to a specific, experimentally determined amount of substance, it is not surprising that the various handbooks of chemical data contain extensive lists of solubilities of various substances. In looking at such data in a handbook, you will notice that the *temperature* at which the solubility was measured is always given. Solubility *changes* with temperature. For example, if you like your tea extra sweet, you have undoubtedly noticed that it is easier to dissolve two teaspoons of sugar in hot tea than in iced tea. For many substances, the solubility increases with increasing temperature. For a number of other substances, however, the solubility decreases with increasing temperature.

For convenience, **graphs** of solubilities are often used rather than lists of solubility data from a handbook. A graph of the solubility of a substance versus the temperature will clearly indicate whether or not the solubility increases or decreases as the temperature is raised. If the graph is carefully prepared, the specific numerical solubility may be read from the graph.

It is important to distinguish experimentally between *whether* a substance is soluble in a given solvent, and *how fast* or *how easily* the substance will dissolve. Sometimes an experimenter may wrongly conclude that a salt is not soluble in a solvent, when actually the solute is merely dissolving at a very slow rate. The *speed* at which a solvent dissolves has nothing to do with the final *maximum quantity* of solute that can enter a given amount of solvent. In practice, we use various techniques to speed up the dissolving process, such as grinding the solute to a fine powder or stirring/shaking the mixture. Such techniques will *not* affect the final amount of solute that ultimately dissolves, however.

The solubility of a salt in water represents the amount of solute necessary to reach a state of *equilibrium* between saturated solution and undissolved additional solute. This number is a *constant* for a given solute/solvent combination at a constant temperature.

SAFETY PRECAUTIONS

- **Wear safety glasses at all times while in the laboratory.**
- **Use glycerine when inserting the thermometer through the stopper. Protect your hands with a towel.**
- **Some of the salts used in this experiment may be toxic. Wash your hands after use. Dispose of the salts as directed by the instructor.**

Apparatus/Reagents Required

8-inch test tube fitted with 2-hole cork or slotted stopper, copper wire for stirring, thermometer, 50-mL buret, salt for solubility determination

Procedure

Record all data and observations directly in your notebook in ink.

Obtain a salt for the solubility determination. If the salt is presented as an *unknown,* record the code number in your notebook (otherwise, record the formula and name of the salt). If the salt is not finely powdered, grind it to a fine powder in a mortar.

Fit an 8-inch test tube with a 2-hole stopper (either cork or slotted rubber). Using glycerine, insert your thermometer (*Caution!*) in one of the holes of the stopper in such a way that the thermometer can still be read from 0° to 100°C. This may involve making a slot in the stopper through which the thermometer can be read.

Obtain a length of heavy-gauge copper wire for use in stirring the salt in the test tube. If the copper wire has not been prepared for you, form a loop in the copper wire in such a way that the loop can be placed around the thermometer when in the test tube. Fit the copper wire through the second hole in the stopper, making sure that the hole in the rubber stopper is big enough that the wire can be easily agitated in the test tube. (See Figure 1-1.)

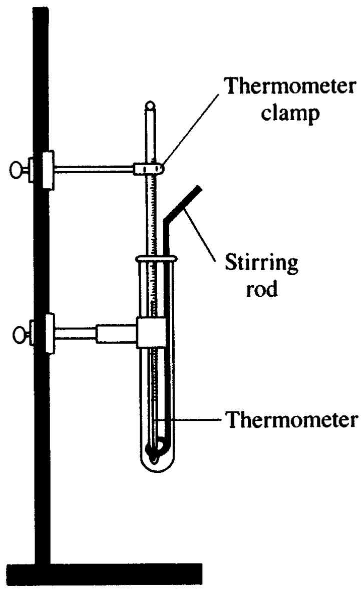
Place about 300 mL of water in a 400-mL beaker, and heat the water to boiling.

While the water is heating, weigh the empty clean, dry 6-inch test tube (*without* the stopper/thermometer/stirring assembly). Make the weight determination to the nearest milligram (0.001 g).

Add approximately 5 g of your salt for the solubility determination to the test tube, and reweigh the test tube and its contents. Again, make the weight determination to the nearest milligram.

Clean the buret with soap and water, and then rinse the buret with tap water, followed by several rinses with distilled water. Fill the buret with distilled water. Make sure that water flows freely from the stopcock of the buret, but that the stopcock does not leak.

FIGURE 1-1
Apparatus for stirring a soluble salt. Be ceratin the thermometer bulb dips into the solution being measured.



Record the reading of the initial water level in the buret to the nearest 0.02 mL. (Recall that water makes a meniscus. Read the water level across the *bottom* of the meniscus.)

In the following procedure, record in your notebook *each time* a portion of water is added from the buret. It is essential to know the amount of water used in the determination.

Add 3.00 $\pm$ 0.01 mL of water from the buret to the salt in the test tube. Record the precise amount of water used.

Attach the stopper with thermometer and stirrer, and clamp the test tube vertically in the boiling water bath. Adjust the thermometer so that the bulb of the thermometer will be *immersed* in the solution in the test tube. The test tube should be set up so that the contents of the test tube are immersed fully in the boiling water. See Figure 1-1. Using the stirring wire, gently stir the salt in the test tube until it dissolves.

If the salt does not dissolve completely after several minutes of stirring in the boiling water bath, remove the test tube and add 1.00 $\pm$ 0.01 mL additional water from the buret. Record. Return the test tube to the boiling water bath and stir.

If the salt is still not completely dissolved at this point, add 1.00 $\pm$ 0.01 mL water portions (one at a time) until the salt just dissolves. Record.

When all the salt has been dissolved at the boiling water temperature, the solution will be *nearly* saturated, and will *become* saturated when the heating is stopped. Minimize the amount of time the test tube spends in the boiling water bath to restrict any possible loss of water from the test tube by evaporation.

After the salt has dissolved completely, raise the test tube out of the boiling water. With constant stirring, allow the solution in the test tube to cool spontaneously in the air. Observe the temperature of the solution carefully, and note the temperature where the *first crystals of salt begin to form.*

The first formation of crystals indicates that the solution is saturated at that temperature. Reheat the test tube in the boiling water, and make a second determination of the temperature at which the first crystal forms. If your results disagree by more than one degree, reheat the solution and make a third determination.

Add 1.00 ± 0.01 mL of additional water to the test tube. Record. Reheat the test tube in boiling water until all the solid has redissolved.

Remove the test tube from the boiling water and allow it to cool again spontaneously. Make a determination of the saturation temperature for solution in the same manner as indicated earlier. Repeat the determination of the new saturation temperature as a check on your measurement.

Repeat the addition of 1.00-mL water samples, with determination of the saturation temperatures, until you have at least six sets of data. Keep accurate records as to how much water has been added from the buret at each determination.

If the saturation temperature drops sharply on the addition of the 1.00-mL samples, consult with the instructor about reducing subsequent additions of water to only 0.50-mL increments. If the saturation temperature does not change enough on the addition of 1.00-mL samples, increase the size of the water samples added to 2.00-mL increments. Keep accurate records of how much water is added.

From your data at each of the saturation temperatures, calculate the *mass of salt that would dissolve in 100 g of water* at that temperature. Assume that the density of water is exactly 1.00 g/mL, so that your buret additions in milliliters will be equivalent to the weight of water being added.

On a piece of graph paper, plot the solubility curve for your salt, using saturation temperatures on the horizontal axis and solubilities per 100 g of water on the vertical axis. Attach the graph to your laboratory report.

The Solubility of a Salt

Date: .... Student name: ....
Course: .... Team members: ....
Section: ....
Instructor: ....

Prelaboratory Questions

1. Using a handbook of chemical data, look up the solubilities of the following salts, per 100 g of water at 20°C.

   NH_4Cl .... Reference ....

   $(NH_4)_2SO_4$ .... Reference ....

   K_2SO_4 .... Reference ....

   KCl .... Reference ....

   KBr .... Reference ....

2. Find a specific definition in your textbook for the following terms:

   Saturated solution

   Solubility

3. Why does stirring affect the rate at which a salt dissolves in water, but not the solubility of the salt in water?

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Date: .... Student name: ....
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Results/Observations

mL of water used	Saturation temperature	Solubility (g/100 g H_2O)

Identity of the salt ....

Literature solubility (20°C) .... Reference ....

Percentage error in solubility at 20°C ....%

Questions

1. The solubility of many salts increases as the temperature increases. How do the solubilities of gases vary with temperature?

2. Why is it better to determine the saturation temperature while the temperature is dropping, rather than while it is rising?

3. When adding water to the salt initially, you attempted to find the minimum amount of water the salt would dissolve in at 100°C. Why was it necessary that the solution to be used be almost saturated?

4. The procedure indicated that the amount of time the test tube was kept in the boiling water bath should be minimized. Why was this necessary?