# THE SOLUBILITY OF A SALT IN WATER
# AT VARIOUS TEMPERATURES

## OBJECTIVE

To measure the solubility of a salt in water over a range of temperatures and to construct a graph representing the salt solubility.

## THEORY

One of the most common forms of a homogeneous mixture is a solution.  The one component of a solution, which is usually present in the greatestr proportion, is called the *solvent*.  The other components, present on a smaller scale, called *solutes*, are considered to be dissolved in the solvent.  There are a number of different kinds of solutions: gases in gases (example: air), liquid in liquids (example: gasoline), gases in liquids (example: carbonated soft drinks), solids in solids (example: alloys such as brass), and solids in liquids (example: salt water).  This experiment will involve a solution formed with a solid solute (a chemical salt) and a liquid solvent (water).

If the properties of a solution remain constant, the system of solute and solvent is considered to be at equilibrium.  Obviously, if the solid is disappearing into the solvent, the system is not at equilibrium. Solubility of a solid in a liquid is dependent on temperature, thus, at a given temperature, only a certain maximum amount of solute will dissolve in a given amount of solvent.  Beyond that amount of solute, no more will dissolve and excess solute will remain in the solid form, settling to the bottom of the solution container.  This maximum amount of dissolved solute, expressed quantitatively, is given in units of grams of solute/100 g of solvent.  Such a solution is termed a *saturated solution*, since it is holding all the solute it can hold at that temperature.  Experiments show that when excess solute is in contact with a saturated solution, an equilibrium is established in which solute is continually dissolving in amounts just equal to the solute separating from solution (crystallization) (see Figure 1).

When saturated solutions of solid solutes are prepared at elevated temperatures and then permitted to cool, the excess solute usually separates from the solution by crystallizing.  However, if a saturated solution is prepared at an elevated temperature and any excess, undissolved solute is removed, crystallization often does not take place when the solution is allowed to cool undisturbed.  The solution can contain more of the solute than normally is held in equilibrium with the solid state.  Such solutions are said to be *supersaturated*.  A supersaturated solution is a system in a metastable (unstable) condition. Agitation of the solution or the addition of a seed crystal of the solute may start crystallization of the excess solute.  After crystallization, a saturated solution remains.

In general, when a solution, which is nearly saturated with a solid solute is cooled, a temperature is reached at which the solution becomes saturated.  On further cooling, the excess solute will crystallize, and will appear as particles separated from the solution.  For solutions of various salts in water it has been found that temperature effects on solubility vary from salt to salt.  Salts are usually more soluble at elevated temperatures than at lower temperatures.  In addition, the change in solubility for a given salt, say between 20° and 30°C, may not be the same as the change in its solubility between 50° and 60°C. To fully characterize the solubility properties of a salt of interest, the chemist must gather data from experimental measurements, such as those described in the next section.
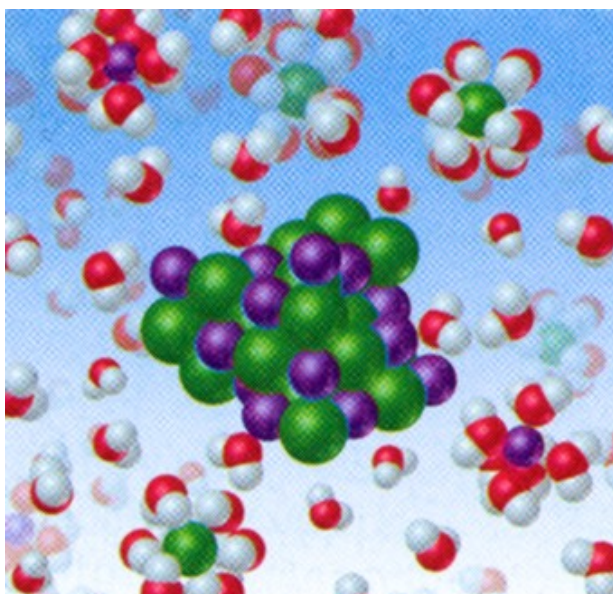
In an unsaturated solution, collisions of the solvent molecules with the crystal loosen particles of the solid which dissolve in the solvent and are hydrated (surrounded) by the solvent molecules. During this process, the crystal decreases in size.

In a saturated solution, there is an equilibrium condition where some particles are leaving the crystal and others are deposited on the surface of the crystal.  The crystal does not change in size, but, over time, may become more regular in shape.

In a supersaturated solution, particles of the solid are being deposited on the surface of the crystal.  The crystal will increase in size as the process continues.

**Figure 1**.  The solution process

## APPARATUS AND CHEMICALS

One of the following salts:
    Ammonium chloride, $NH_4Cl$
    Potassium chlorate, $KClO_3$
    Potassium nitrate, $KNO_3$
    Sodium phosphate, $Na_3PO_4$
    Sodium sulfate, $Na_2SO_4$
ice
large test tube, 25 x 200 mm
clamps: utility and thermometer
Bunsen burner
copper or nichrome wire (for stirrer)
110°C thermometer or temperature probe and computer
distilled water
10-mL graduated cylinder
beaker, 250 or 400 mL
ring stand

## SAFETY PRECAUTIONS

Potassium chlorate and potassium nitrate are oxidizers, do not allow them to come in contact with combustible materials.

## Disposal

Dispose of all materials in the appropriate waste containers. Do not throw any solid material in the trash.

## PROCEDURE

Assemble the apparatus as shown in Figure 2. The preferred set-up uses a thermometer clamp to hold the thermometer or temperature probe. If a thermometer clamp is not available, place the thermometer in a split one-hole rubber stopper and support it using a utility clamp. The thermometer is adjusted so that the bulb is between 1 and 2 cm from the bottom of the large test tube. Make sure you have a clear view of the temperature scale between 20° and 100°C. To prepare the wire stirrer, bend a loop in one end of the wire slightly smaller than the inside diameter of the tube and bend it at a 90° angle to the wire. The wire loop should be positioned around the thermometer bulb. **Note:** Once the apparatus is assembled, it is not to be taken apart until the experiment is completed.

Select one salt to use, either
  Ammonium chloride, $NH_4Cl$
  Potassium chlorate, $KClO_3$
  Potassium nitrate, $KNO_3$
  Sodium phosphate, $Na_3PO_4$
  Sodium sulfate, $Na_2SO_4$

Weigh out approximately 5.0 g of the salt, record the mass of the salt to the nearest 0.001g, and add it to the clean dry test tube.

Measure 4.0 mL of distilled or deionized water in a 10-mL graduated cylinder. Determine the exact mass of water by weighing the 10-mL graduated cylinder and the water, adding the water to the test tube containing the salt, and reweighing the empty, but wet, graduated cylinder. The difference between the mass of the graduated cylinder and water and mass of the empty cylinder is the mass of water added. This procedure will be followed for each addition of water for subsequent trials.

Heat the test tube and its contents, stirring while you heat. Continue heating until all of the salt has dissolved, but do not exceed a temperature of 95°C. **DO NOT ALLOW THE SOLUTION TO BOIL**. If the temperature has reached 95°C, and the salt has not dissolved completely, stop heating, obtain 1 mL of water, weight it according to the procedure in the step above, and add it to the test tube. The first addition of
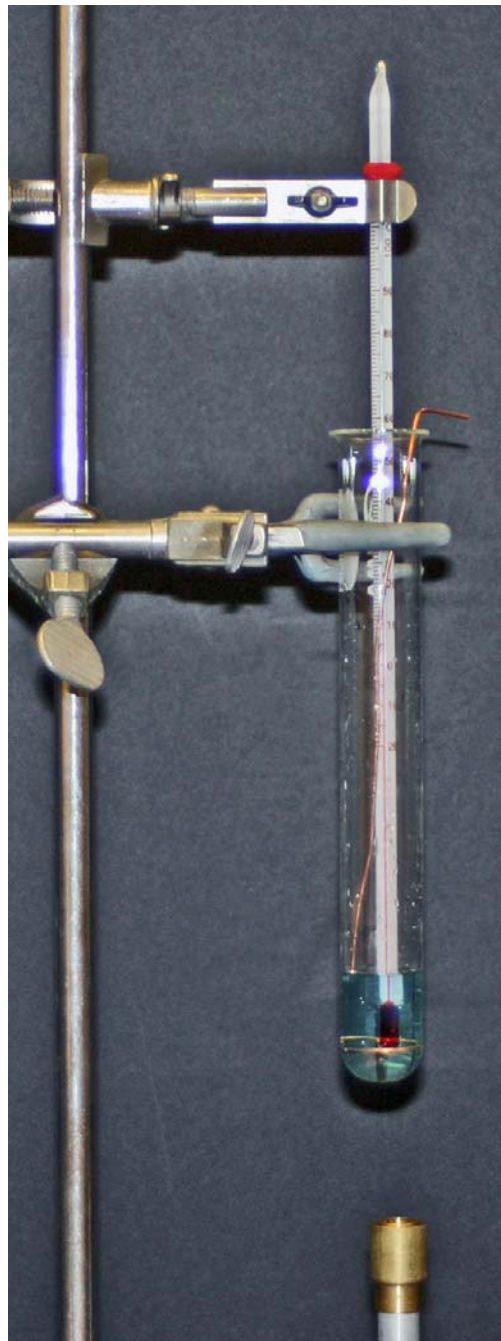
**Figure 2**. Set-up for measuring solubility of a salt

water will be the sum of the two masses of water added.  (Note: Depending on the salt selected, it may be necessary to add additional 1 mL increments of water to effect the first solution.)

When all of the salt has dissolved, stop heating and continue to stir.  Watch the solution as it cools for the appearance of small crystals of salt.  When crystals first appear, note the temperature of the solution and record it.  **Do not disassemble the apparatus.**

Measure 2.0 mL of water  in the 10-mL graduated cylinder, weigh the cylinder and water, add the water to the test tube, then weigh the empty graduated cylinder.  The difference between the two masses is the mass of water added to the test tube.  Calculate the total mass of water in the test tube. Repeat the heating and cooling cycle, noting the temperature of crystallization.  (Note: You can increase the rate of cooling by bringing a beaker of room temperature water up to the bottom 2 cm of the test tube for **5 seconds**.  Allow the temperature of the solution to stabilize for a minimum of 30 seconds between cooling with the beaker of water.)

Repeat the procedure of adding weighed 2.0 mL increments of water, heating, and cooling for a total of 10 measurements or until the saturation temperature is below 20°C.  If the temperature of the solution is approximately 20°C and no crystallization occurs, the test tube can be cooled by bringing a beaker of cold or ice water up to the bottom 3 or 4 cm of the test tube.  Cool the mixture for no more than 5 seconds each time, stirring, until the salt crystallizes.
**NOTE:** If the addition of 2 g of water does not change the saturation temperature of the solution by approximately 10°C, increase the additions of water to 3 g or 4 g.


## Calculations

Calculate the concentration (in g salt/100 g solvent) of the solution at each saturation temperature.

$$g\ salt\,/100\ g\ solvent\ =\ \frac{mass\,of\ salt\,used,g}{total\,mass\,of\ water,g}\times100$$

Consult a *Handbook of Chemistry*, a *Handbook of Chemistry and Physics*, or the Internet to find the actual solubility of the salt you used at various temperatures.

# SOLUBILITY OF A SALT IN WATER
# AT VARIOUS TEMPERATURES

## Data:

salt used (write formula) _____

mass of salt used _____ g

**Trial 1:**

mass of 10-mL grad. cyl. + 1st addition of water _____ g

mass of 10-mL grad. cylinder _____ g

mass of water added to test tube _____ g

mass of water present (total) _____ g

saturation temperature _____°C

**Trial 2:**

mass of 10-mL grad. cyl. + 2nd addition of water _____ g

mass of 10-mL grad. cylinder _____ g

mass of water added to test tube _____ g

mass of water present (total) _____ g

saturation temperature _____°C

**Trial 3:**

mass of 10-mL grad. cyl. + 3rd addition of water _____ g

mass of 10-mL grad. cylinder _____ g

mass of water added to test tube _____ g

mass of water present (total) _____ g

saturation temperature _____°C

**Trial 4:**

mass of 10-mL grad. cyl. + 4th addition of water _____ g

mass of 10-mL grad. cylinder _____ g

mass of water added to test tube _____ g

mass of water present (total) _____ g

saturation temperature _____°C

**Trial 5:**

mass of 10-mL grad. cyl. + 5th addition of water          _____ g

mass of 10-mL grad. cylinder          _____ g

mass of water added to test tube          _____ g

mass of water present (total)          _____ g

saturation temperature          _____ °C

**Trial 6:**

mass of 10-mL grad. cyl. + 6th addition of water          _____ g

mass of 10-mL grad. cylinder          _____ g

mass of water added to test tube          _____ g

mass of water present (total)          _____ g

saturation temperature          _____ °C

**Trial 7:**

mass of 10-mL grad. cyl. + 7th addition of water          _____ g

mass of 10-mL grad. cylinder          _____ g

mass of water added to test tube          _____ g

mass of water present (total)          _____ g

saturation temperature          _____ °C

**Trial 8:**

mass of 10-mL grad. cyl. + 8th addition of water          _____ g

mass of 10-mL grad. cylinder          _____ g

mass of water added to test tube          _____ g

mass of water present (total)          _____ g

saturation temperature          _____ °C

**Trial 9:**

mass of 10-mL grad. cyl. + 9th addition of water          _____ g

mass of 10-mL grad. cylinder          _____ g

mass of water added to test tube          _____ g

mass of water present (total)          _____ g

saturation temperature          _____ °C

**Trial 10:**

mass of 10-mL grad. cyl. + 10th addition of water        _____ g

mass of 10-mL grad. cylinder        _____ g

mass of water added to test tube        _____ g

mass of water present (total)        _____ g

saturation temperature        _____°C

## Summary and Calculations

salt used _____      mass of salt used _____

| Trial | Mass of water present g | Solution concentration g salt/100 g $H_2O$ | Saturation Temperature °C |
|-------|-------------------------|---------------------------------------------|---------------------------|
| 1     | _____    | _____                        | _____     |
| 2     | _____    | _____                        | _____     |
| 3     | _____    | _____                        | _____     |
| 4     | _____    | _____                        | _____     |
| 5     | _____    | _____                        | _____     |
| 6     | _____    | _____                        | _____     |
| 7     | _____    | _____                        | _____     |
| 8     | _____    | _____                        | _____     |
| 9     | _____    | _____                        | _____     |
| 10    | _____    | _____                        | _____     |

Plot your data on graph paper or use Microsoft Excel. Draw a smooth curve to best fit the points Plot the saturation temperature (C°) on the horizontal axis and the concentration (g salt/100g water) on the vertical axis. Your graph should include title, axis labels, and units of measure.

Also, plot the actual solubility of the salt on the same axes.

How does your result compare with the reference values?

Predict from your graph the solubility of the salt at 20°C in g salt/100 g $H_2O$

Predict from your graph the solubility of the salt at 50°C in g salt/100 g $H_2O$

List possible sources of error in determining the solubility of a salt in water at various temperatures and discuss one of them as to how it would influence the results you obtained.