Laboratory 6: Physical and Chemical Solubility

Topics Covered

- Physical solubility
- Chemical solubility
- Like dissolves like
- Polarity

Equipment Needed (per pair or group)

- Weighing scale (readable to 0.01 g)
- bunsen burner
- ring stand, ring and wire gauze
- 4 test tubes, 20 ml
- tube holder and rack
- 2 thermometers
- graduated cylinder
- marker (for labeling test tubes)
- glass stirring rod
- 250 ml beaker

Reagents Needed (per pair or group)

- 20 grams potassium nitrate

Background Information -- Physical Solubility

Solubility can be a fairly complex subject. Basically you have a solute (gas, liquid or solid) that mixes with or dissolves in a solvent (usually a liquid) to form a homogeneous solution. The amount of solute that can be dissolved in the solvent is called the solubility of that particular solute in that particular solvent. For example, the solubility of sugar (sucrose) in water is about 2 grams/mL at room temperature. That's a lot, considering one mL of water weighs only 1 gram.

Sucrose is a molecular solid with the formula $C_{12}H_{22}O_{11}$. A clump of sugar is made up of thousands of individual molecules held together by weak intermolecular forces or bonds. When it dissolves in water, the bonds are broken and individual molecules are released (dissociate from one another) into the water (equation 1). When enough sugar has been added to reach the solubility level it is said to be saturated, meaning no more sugar will go into solution.

$$\text{Equation 1} \quad C_{12}H_{22}O_{11}(s) \xrightarrow{H_2O} C_{12}H_{22}O_{11}(aq)$$

Table salt or sodium chloride (NaCl) is an ionic solid that dissociates into its positive and negative ions when dissolved in a liquid (see equation 2). The solubility of salt in water at room temperature is about 0.3 grams NaCl/g H_2O.

$$\text{Equation 2} \quad NaCl(s) \xrightarrow{H_2O} Na^{+}(aq) + Cl^{-}(aq)$$

Solubility is temperature and pressure dependent. Generally, as the temperature and pressure increase, the solubility of one substance in another will increase. For example the solubility of sugar in hot water can go up to as much as 5 grams/g of water (see figure 1). The solubility graph for NaCl vs. temperature is fairly flat but does increase slightly from 0 to 100°C.

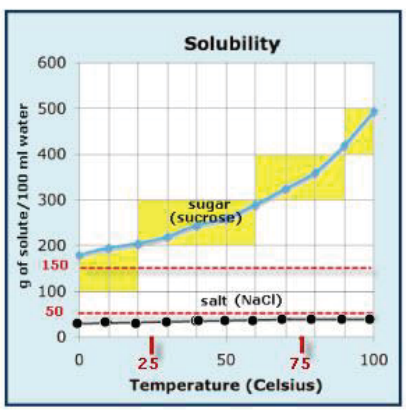


Figure 1. Solubility vs. temperature of sugar and salt in water.

Solubility can be expressed in units of concentration, molality, mole fraction, mole ratio, and other units. Once the solubility limit or saturation is achieved, the solute will begin to precipitate out as more is added or if the solution begins to cool. Solubility levels can range from infinitely soluble (miscible) such as ethanol in water, to insoluble such as oil and water. Technically a small amount of water is soluble in oil.

A useful rule of thumb for predicting solubility is "like dissolves like," meaning a solute will dissolve best in a solvent that has similar chemical characteristics. One of these characteristics is polarity. A highly polar solute like sugar is very soluble in highly polar water, less soluble in fairly polar methanol, and insoluble in non-polar hexanes. Similarly, non-polar oil is very soluble in non-polar hexanes, less soluble in fairly polar methanol, and insoluble in very polar water.

The term hydrophilic, meaning “attracted to water,” is somewhat synonymous to polar. Polar molecules are hydrophilic and are typically charged and capable of hydrogen bonding, enabling them to dissolve in water. Non-polar molecules are hydrophobic, “afraid of water,” and generally do not dissolve in water or other polar solvents. Some molecules have characteristics of both. Soap, for example, is a long molecule that has a polar head and a non-polar tail, allowing it to dissolve in both water and oil. As you may know, it is very useful for cleaning non-polar oil and grease off your hands with polar water.

Background: Chemical Solubility

A solution can be formed through dissolution, but it can also be formed because of a chemical reaction. This is what distinguishes chemical solubility from physical solubility as in the sugar or salt in water examples. The process of making biodiesel gives us several examples of chemical solubility.

For example, a catalyst is generally needed for the transesterification reaction for making biodiesel. One of the typical catalysts used for this is prepared by dissolving sodium hydroxide (NaOH) in methanol. The resulting solution is the product of a chemical reaction between the NaOH and the methanol that forms sodium methylate and water.

Equation 3 $CH_3OH + NaOH \rightarrow CH_3ONa + H_2O$

The biodiesel reaction between methanol and triglycerides (oils and fats) goes through different stages of solubility between the reactants and the products of reaction (methyl esters and glycerol). Initially methanol is not soluble in oil. However, as the reaction begins, mono and diglycerides as well as methyl esters are formed and act as co-solvents to allow the methanol and oil to become soluble in each other. As the reaction progresses, free glycerol is produced, which is not soluble in the methyl esters.

Also a side reaction occurs, which produces some soap. You end up with two phases: the lighter phase contains a solution of mostly methyl esters, some methanol, a little soap, and very little glycerol. The heavy phase contains a solution of mostly glycerol, some methanol, some soap, and very little methyl esters. The methanol, which is somewhat polar, will dissolve in both the non-polar esters and the polar glycerol. The soap (which has properties of both) is responsible for a little glycerol in the ester phase and a little of the esters in the glycerol phase.

Pre-Lab Questions

- How is the solubility of sugar in water affected by increasing the temperature?
- What does the phrase "like dissolves like" mean?
- How is solubility expressed?
- What is the difference between a saturated and an unsaturated solution?

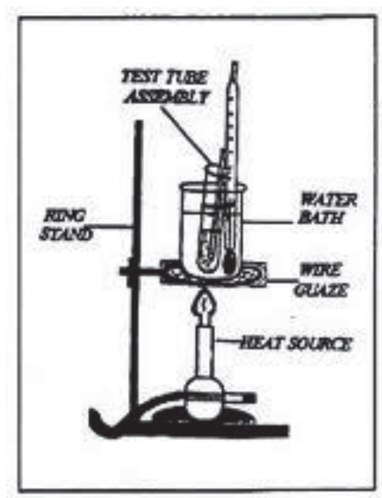
Safety Note: Potassium nitrate can irritate the eyes, skin, and lungs. Wear eye protection, gloves, a mask, and a lab coat when handling this chemical.

Laboratory Procedure

1. Number four test tubes and place in rack.
2. Weigh KNO_3 and water into the four tubes as indicated in table 1.

Table 1

Tube #	KNO_3, g	DI water, mL
1	2	5
2	4	5
3	6	5
4	8	5



Heating Assembly↑

3. Prepare a water bath by filling a 250 ml beaker ¾ full of water. Place on ring stand as shown in figure 2 and heat to 90^{o} C.
4. Place each test tube in turn or all 4 together in the water bath and stir with a glass stir rod until the KNO_3 is dissolved.
5. Take each one out of the bath in turn along with a hot, dry thermometer placed into the solution and observe the first sign of crystallization as it cools. Record the temperature in table 2.

Table 2

Tube #	KNO_3/H_2O	Crystallization temp °C
1	2g + 5mL	
2	4g+ 5mL	
3	6g+ 5mL	
4	8g+ 5mL	

Data Processing

Now you are going to use the information you discovered to draw a solubility vs temperature curve. The Y axis (solubility) is often expressed in grams of solute /100mL H_2O.

First convert your data into (g KNO_3:100mL H_2O) ratio. As an example a 2:5 ratio would equal a 40:100 ratio. Next, plot your data and draw the solubility curve for KNO_3 vs. temperature.