Experiment 5
Freezing Point Depression

OUTCOMES

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

- determine the freezing point of a pure solvent and a solution.
- calculate the freezing point depression constant, K_f, of a solvent.

DISCUSSION

The physical properties of solutions that depend on the number of dissolved solute particles and not their specific type are known as **colligative properties**. These include freezing point depression, osmotic pressure, and boiling point elevation. In today's experiment, you will explore the changes in freezing point behavior of solutions in which t-butyl alcohol (2-methyl-2-propanol) is the solvent.

Freezing point depression occurs when a solute is added to a solvent producing a solution having a lower freezing point temperature than the pure solvent. The temperature decreases by an amount ΔT_f given by the following formula:

$$\Delta T_f = K_f \, m \, i$$

where K_f is the freezing point depression constant (characteristic of the solvent), m is the **molal** concentration of the solution in moles of solute per kilogram of solvent (mol/kg), and i is the van't Hoff factor which indicates how many particles a given solute breaks apart into when dissolved in solution. One way to understand the freezing point depression effect is to consider the solute particles as interfering or standing between the solvent particles. With greater space between solvent particles, intermolecular forces are weaker. Consequently, lower temperatures are required to make it possible for solvent particles to approach each other and form the solid. It is important to note the identity of solute particles is not specified. That is, an aqueous 0.50 m $C_6H_{12}O_6$ solution should have the same freezing point as an aqueous 0.25 m NaCl solution, since each formula unit of NaCl provides two ions in solution (i = 2).

In today's experiment, you will first determine the freezing point of the t-butyl alcohol by cooling it in cold water. You will then add a solute to the alcohol and measure the freezing point of the solution. After determining the freezing point and actual ΔT_f of the solution and the masses of solute and solvent, you should be able to determine the K_f of the solvent.

PROCEDURE

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

⚠ ***Avoid skin contact with the chemicals in this experiment.***

1. Connect a temperature probe to Channel 1 of the Vernier *LabPro®* interface and launch the *LoggerPro* application. If the temperature probe is not automatically identified by the software and interface, open the file for the stainless steel temperature probe from the **Probes & Sensors** folder of the **Experiments** folder.

2. Adjust the experiment length to 10 minutes and the sampling rate 10 samples/min.

3. Prepare a warm/hot water bath to warm the liquid before each run to a temperature between 40 and 50 °C.

4. Prepare an ice bath in a 400-mL beaker.

Procedure 1: Determining the Freezing Point of Pure t-Butyl Alcohol

1. Measure and record the mass of a clean, dry large test tube by standing it in a beaker or an Erlenmeyer flask. Using a graduated cylinder, pour 20 mL of t-butyl alcohol into the test tube and measure the new mass.

2. Clamp the test tube to a ring stand. Insert a clean, dry copper stirrer into one hole of a two-hole stopper and stopper the test tube. Into the second hole of the stopper, clamp a clean, dry temperature probe into the test tube. Make sure that the probe does not touch the walls of the test tube and yet is still well-immersed in the liquid. The copper stirrer should surround the probe.

3. Warm the test tube in the warm bath to the desired temperature range.

4. When you are ready to begin data collection, click on the green "Collect" button. Quickly lower the test tube into the cold water bath. Continuously stir the contents of the test tube with an up/down motion. Make sure the probe remains in the liquid and that it does not come into contact with the walls of the test tube. Stir as long and consistently as possible, allowing the data collection to continue until the temperature levels off or a long, gradual slope is obtained (see Figure 1 in Data Analysis).

5. Click on the red "Stop" button. Remove the test tube from the cold water bath. Under the Experiment menu, select Store Latest Run. Save your file.

6. Repeat steps 3 - 5 so that you have obtained two trials for the pure t-butyl alcohol.

Procedure 2: Determining the Freezing Point of a t-Butyl Alcohol Solution

1. Remove the test tube from the clamp and dry it thoroughly. To account for any t-butyl alcohol that may have evaporated or otherwise been lost, measure and record the mass of the test tube and contents on the same balance as before to determine the mass of t-butyl alcohol remaining.

2. Add 1.00 to 1.50 g of one of the available solutes to the t-butyl alcohol. Use a dropper to add a liquid or a spatula to add a solid. Measure and record the precise mass used by reweighing the test tube and contents. Mix the contents of the test tube thoroughly to ensure the complete dissolution of the solute. Make sure the solute is not sticking to the sides of the test tube and is completely dissolved before proceeding.

3. Clamp the test tube into place with the clean and dry stirrer and probe assembly.

4. Replace any melted ice in the ice water bath.

5. Warm the test tube in the warm bath to the desired temperature range.

6. When you are ready to begin data collection, click on the green "Collect" button. Quickly lower the test tube into the cold water bath. Continuously stir the contents of the test tube with an up/down motion. Make sure the probe remains in the liquid and that it does not come into contact with the walls of the test tube. Stir as long and consistently as possible, allowing the data collection to continue until the temperature levels off or a long, gradual slope is obtained.

7. Click on the red "Stop" button. Remove the test tube from the cold water bath. Under the Experiment menu, select Store Latest Run. Save your file.

8. Repeat steps 5 - 7 so that you have obtained two trials for the t-butyl alcohol solution.

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

DATA ANALYSIS

As the pure solvent cools, its temperature drops. This is illustrated in the graph to the left in Figure 1. During the conversion of liquid to solid, the temperature remains relatively constant and a plateau in the cooling curve is observed. The average temperature of the plateau is the freezing point of the pure solvent.

The freezing point of a solution is the temperature at which crystals just begin to form. As additional solid forms, the temperature continues to drop. This behavior is illustrated in the graph to the right in Figure 1. Since the temperature probe is unable to respond instantly to temperature changes, the thermometer records a gradual change in temperature instead of the abrupt change that should be observed at the instant crystals begin to form. Consequently, the graph is rounded in the vicinity of the appearance of crystals. To compensate for the slow response of the thermometer, the solution's freezing point is determined graphically. The freezing point of the solution is found at the intersection of two "straight-line" series of the cooling curve: the first includes data obtained as the solution cools and approaches the freezing point and the second includes data obtained as the solution solidifies.

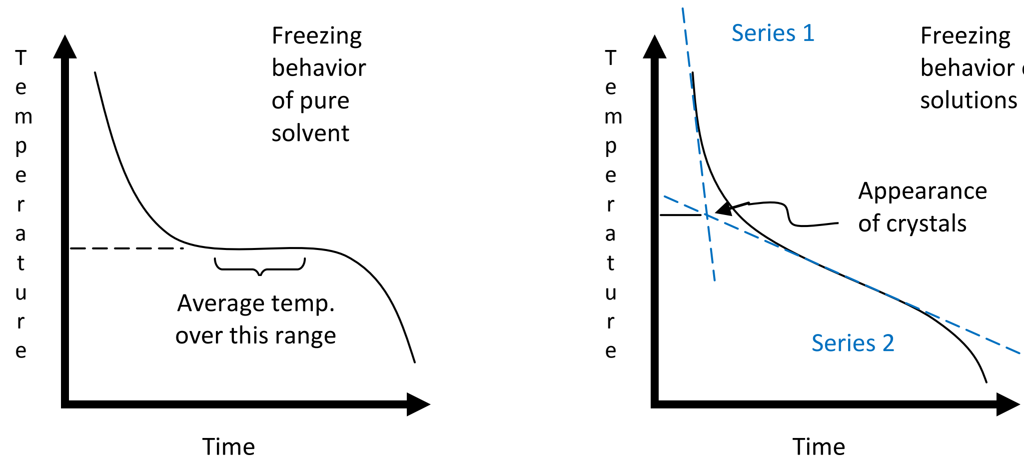

Figure 1. Comparison of freezing behavior of pure solvents and solutions.

1. Using your data and LoggerPro, find the average of the temperatures over the plateau for each trial of pure t-butyl alcohol from Procedure 1. To do this, highlight the range that looks flat and then click on Stat button (see Figure 2). Choose the appropriate run and then record the average given in the text box that appears. You can click on the brackets marking the range of which you are taking the average and slide them forward or back if you want to make adjustments to the range. Record the temperature for each trial of pure t-butyl and calculate the average freezing point of t-butyl alcohol.

2. Using your data and LoggerPro, determine the freezing point of the t-butyl alcohol solutions. To do this, highlight a range that looks linear for Series 1 for one of your trials and click on the linear regression button (see Figure 2). Choose the appropriate run and a box will open up which will give the slope and y-intercept for the line. You can click on the brackets marking the range chose and slide them forward or back to adjust the line to make it follow the data better. Repeat this for Series 2 of the same trial to obtain two intersecting lines. To determine where they intersect, you can solve the equations of the two lines simultaneously or by substitution. Alternatively, you may highlight the area where they intersect on the graph and zoom in using the Zoom In button. Placing your cursor over the intersection of the two lines will give the appropriate *x*- and *y*-coordinates in the bottom left corner of the graph. Determine the freezing point for *each trial* of the t-butyl alcohol solution.

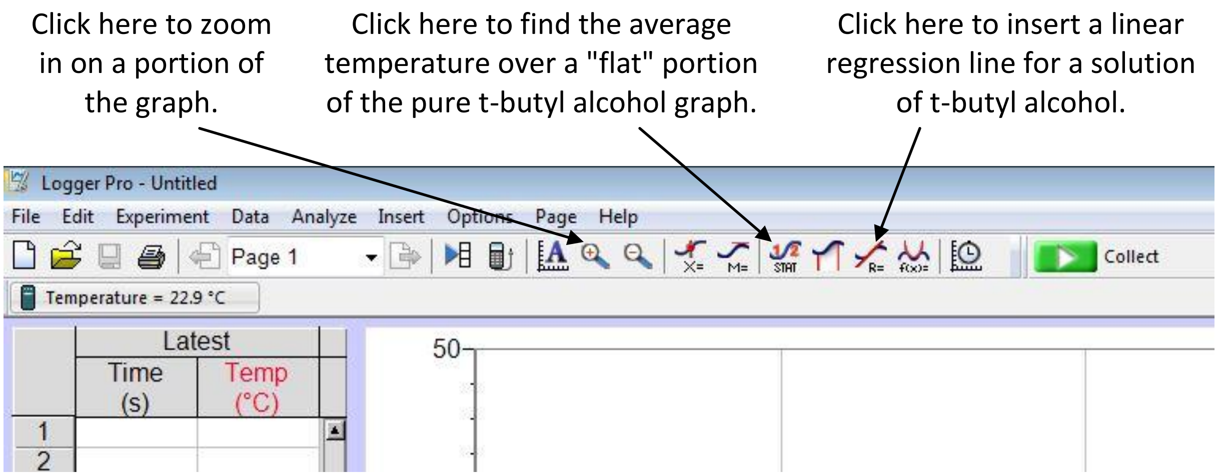

Figure 2. Graphical analysis using LoggerPro.

3. Calculate the molality (m) and the freezing point depression (ΔT_f) for **each trial** of the solutions.

4. Using the molality and the freezing point depressions, calculate the freezing point depression constant (K_f) for each trial of the solutions. Find the average value for K_f based on your data and submit your average K_f value.

5. Gather all of the K_f values from your lab section and calculate the average value of K_f for t-butyl alcohol.

6. How constant was the K_f value for the lab section? Explain.

7. Using the class average for K_f and the freezing point of pure t-butyl alcohol which you determined in the lab, what is the molecular weight of a substance that yields a freezing point of 18.2 °C when 1.06 g of the substance was dissolved in 18.36 g of t-butyl alcohol?

8. A skyscraper in Pittsburgh, built in the early 1970's, is supported by water filled columns. Potassium carbonate was added to the water to prevent freezing in cold weather. If the solution is 40.0% K_2CO_3 by mass, what is the predicted freezing point of this solution in °C, assuming full ionization?

9. Melting point temperatures are frequently used to help identify unknown solids and determine their purity. How would the melting point of a pure solid sample compare to that of the same solid contaminated by a solid impurity? Explain.

POSTLAB ACTIVITY

You will be individually completing a postlab quiz on D2L. While taking the quiz, you will be given data to analyze. Before leaving lab today, your instructor should check your work to make sure that you correctly understand the necessary concepts and calculations before beginning the quiz.