Using Freezing-Point Depression to Find Molecular Weight

When a solute is dissolved in a solvent, the freezing temperature is lowered in proportion to the number of moles of solute added. This property, known as freezing-point depression, is a **colligative property**; that is, it depends on the ratio of solute and solvent particles, not on the nature of the substance itself. The equation that shows this relationship is

\[ \Delta T = K_f \times m \]

where \( \Delta T \) is the freezing point depression defined as \( T^o_f - T_f \). The freezing point of the pure solvent is \( T^o_f \) and the freezing point of the solution is \( T_f \). \( K_f \) represents the freezing point depression constant for a particular solvent (1.86°C•kg/mol for water in this experiment). The concentration of the solution is given in molality, \( m \), in terms of mol solute/kg solvent.

**OBJECTIVES**

In this experiment, you will

- Determine the freezing temperature of the pure solvent, water.
- Determine the freezing temperature of a mixture of water and table sugar.
- Calculate the freezing point depression of the mixture.
- Calculate the molecular weight of sugar.

**MATERIALS**

Vernier computer interface  
computer  
Temperature Probe  
ring stand  
400 mL beaker  
Glass stir rod  
Copper wire stirrer  
Lab jack  
Rock salt  
Sucrose, \( \text{C}_{12}\text{H}_{22}\text{O}_{11} \)  
Ice  
2- 20 × 150 mm test tubes  
2- utility clamps  
Graduated cylinder  
Waste bucket for ice/ salt mixture
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PROCEDURE

1. Put on your chemical splash-proof safety goggles.

2. Connect a Temperature Probe to Channel 1 of the Vernier computer interface. Connect the interface to the computer with the proper cable.

3. Start the Logger Pro program on your computer. Open the file “04 Freezing Point” from the Advanced Chemistry with Vernier folder.

Part I. Determine the Freezing Temperature of Pure Water

4. Fill a 400 mL beaker approximately ¾ full with an ice/salt mixture (alternating 2 cm layers of ice and 1 cm layers of rock salt). Stir this ice-salt mixture and make sure the temperature drops to between -5 °C to -10 °C. This ice bath will be used in each experiment. Be sure to check the temperature of the ice bath before each experiment. If the temperature has risen above -10°C, then drain the water and add more ice and salt. Support the beaker on a lab jack and place both on the base of the ring stand.

5. About between 14 – 15 mL of water into a 20 × 150 mm test tube. The test tube should be about ½ full. Fasten a utility clamp at the top of the test tube and secure to the ring stand.

6. Insert the Temperature Probe into the water in the test tube and secure the probe with another utility clamp to the ring stand so the test tube and probe assembly is above the ice bath. The probe should not come in contact with the glass of the test tube at any time during the experiment.

7. Using a lab jack, raise the ice bath so that the test tube contents are well below the ice/salt mixture. (You may have to make a hole in the ice/salt mixture before the test tube can be inserted.) Make sure the ice/salt level outside the test tube is higher than the water level inside the test tube, as shown in Figure 1. It is essential that the ice/salt mixture be above the level of the water in the test tube and that the test tube remains in contact with the ice/salt mixture.

8. Use a copper wire to continuously stir the water with a very slight up-and-down motion, for the ten-minute duration of the experiment.

9. When the data collection is complete, remove the test tube from the ice bath and remove the Temperature Probe. Carefully wipe any excess water from the probe with a paper towel.

10. The freezing temperature can be determined by finding the mean temperature in the portion of the graph with nearly constant temperature.
   a. Move the mouse pointer to the beginning of the graph’s flat part. Press the mouse button and hold it down as you drag across the flat part of the curve, selecting only the points in the plateau.
   b. Click on the Statistics button, ☐.
   c. The mean temperature value for the selected data is listed in the statistics box on the graph. Record this value as the freezing temperature of the water.
   d. Click on the upper-left corner of the statistics box to remove it from the graph.
Part II. Determine the Freezing Temperature of a Solution of Sugar and Water

11. Prepare the computer for data collection.
   a. From the Experiment menu, choose Store Latest Run. This stores the data so it can be used later.
   Store your data on the supplied diskette.
   b. To hide the curve of your first data trial, click the Temperature vertical-axis label of the graph, and uncheck the Run 1 box. Click OK.

12. Repeat Steps 4-9, using an aqueous sugar solution which is about 15% sugar by mass. Prepare 10 mL of this solution. Record the masses of sugar and water precisely to ±0.01 g.

13. The freezing temperature of the sugar-water solution can be determined by finding the temperature at which the mixture initially started to freeze. Unlike pure water, the mixture results in a gradual linear decrease in temperature during freezing. Follow the steps below to analyze the graph.
   a. Click and drag the mouse to highlight the initial part of the cooling curve where the temperature decreases rapidly (before freezing occurred).
   b. Click on the Linear Regression button,
   c. Now click and drag the mouse over the next linear region of the curve (the gently sloping section of the curve where freezing took place).
   d. Click again. The graph should now have two regression lines displayed.
   e. Choose Interpolate from the Analyze menu. Move the cursor to the point of intersection of the two lines; the temperatures shown in either examine box are equal to the freezing temperature of the sugar-water mixture.
   f. Record the freezing temperature in your data table.
   g. Store your data on the supplied diskette.

14. Print appropriately labeled graphs showing both trials.
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Data Table

<table>
<thead>
<tr>
<th>Freezing temperature of pure water (°C)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of water (g) in solution.</td>
<td></td>
</tr>
<tr>
<td>Mass of sucrose (g) in solution.</td>
<td></td>
</tr>
<tr>
<td>Freezing temperature of the sucrose-water mixture (°C)</td>
<td></td>
</tr>
</tbody>
</table>

Data Analysis

1. Using the collected data, calculate the *experimental* molar mass of sucrose.

2. Calculate the percent error of the *experimental* molecular weight.