Molecular Mass by Freezing Point Depression

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

$$\Delta t = K_{f\,b} \times m$$

where Δt is the freezing point depression, K_f is the freezing point depression constant for a particular solvent, and m is the molality of the solution (in mol solute/kg solvent). The value of K_f must be determined for each solvent. In this experiment, distilled water will be used as the solvent.

The freezing point of distilled water is approximately 0^{o}C. If the freezing point of both the solvent and the solution is determined using a thermometer that is calibrated every 0.1^{o}C, the freezing point can be estimated in the range $\pm\ 0.01^{o}$C. Even though the melting point of distilled water is known, it is necessary to determine it with the thermometer that will be used in this experiment.

Thermometers can give temperature readings that are slightly different from true values. In this experiment, we will be using the change in temperature to calculate the molar mass. Even if the thermometer reading is slightly off, the change in temperature should be accurate. It is important that the same thermometer is used to determine both the freezing point of the solvent and that of the solution.

Figure 1 shows a cooling curve for a pure solvent and for a solution. Notice that supercooling may occur in both the solvent and the solution. If it does, as the crystals begin to form, the temperature will rise slightly and then remain constant as the pure solvent freezes, or it will slowly fall as the solution freezes.

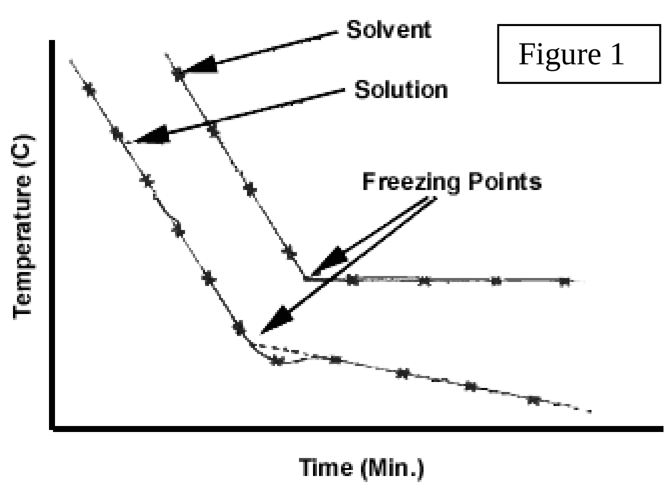

Figure 1

OBJECTIVES

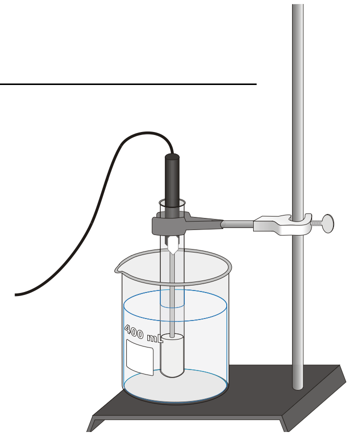

Figure 2

In this experiment, you will

- Determine the freezing temperature of the pure solvent, distilled water.
- Design and carry out an experiment to determine the freezing temperature of a mixture of distilled water and *a non-electrolyte solute*
- Calculate the freezing point depression of the solution containing the solute.
- Calculate the experimental molecular weight of the solute

AVAILABLE MATERIALS

LabQuest interface
TI graphing calculator
Temperature Probe
ring stand
400 mL beaker
tissue or paper towels
Weighing paper
salt
150 mL beakers
Spatula or scoopula

Distilled water
Foam cup
non-electrolyte solutes as available
ice
18 × 150 mm test tubes
utility clamp
Balance, sensitive
Tap water
10 or 25 mL graduated cylinders

SAFETY ALERT

Wear chemical splash goggles.

PROCEDURE

1. Connect a Temperature Probe to Channel 1 of the LabQuest. Connect the LabQuest to a computer, if desired.
2. Set up the data collection in a timed run for 10 seconds per sample and 60 samples.

Design the Experiment

1. Design a procedure to determine the freezing point depression of an aqueous solution. As a group, write out a step by step plan in your lab notebooks. Consider the following

   a) What are your controlled and experimental (test) variables?

   b) How much solvent will you use?

   c) What solute will you use? How much solute will you use?

   d) What measurements do you need to make?

   e) How will you set up your apparatus?

Did you know?
You can prepare an ice bath in a foam cup with ice, table salt and a small amount of tap water. Place the cup in a beaker to give it more stability. The ice bath should be deep enough so that it is above the level of the distilled water in the test tube but well below the mouth of the test tube

2. Design an appropriate data table in your lab notebook before starting the experiment.

3. Discuss your plan with your instructor. Incorporate any suggested changes to your plan.

Part II Implementing the plan

4. Obtain and wear goggles and lab aprons.
5. Record the name and formula of the solute you choose.
6. Carry out the procedure as planned. Record all relevant data and observations directly into your lab notebook. If you made any changes to your original plan, note the changes in your lab notebook.

Did you know?
If you highlight a section of data on the graph and use the "statistics" feature under the analyze tab, the Loggerpro software will calculate the mean temperature!

7. When data collection is complete, use a warm water bath to melt the ice enough to safely remove the temperature probe. Carefully wipe any excess liquid from the probe with a paper towel or tissue.

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8. Store the data from each run.

When data collection is complete, use a warm water bath to melt the substances enough to safely remove the Temperature Probe. Discard all solutions in the sink.

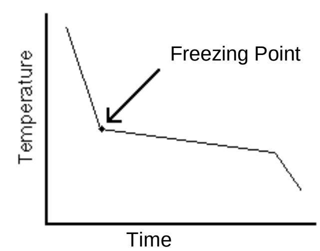
9. Analyze your data to determine the freezing point of the pure solvent and the solution.

DATA ANALYSIS

Show all your work!

1. Calculate the freezing point depression (Δt) for the solution.
2. Calculate molality (m) of the solute, in mol/kg, using the formula $\Delta t = K_f \times m$. The K_f value for distilled water is 1.86°C•kg/mol.
3. Calculate moles of the solute, using the molality and the mass (in kg) of distilled water solvent.
4. Calculate the *experimental* molecular weight of the solute, in g/mol.
5. Determine the *accepted* molecular weight of the solute from its formula.
6. Calculate the percent error between the experimental and accepted values.

Did you know?
Supercooling is common, but the freezing point can be recognized by the relatively constant temperature as the solution becomes mushy. The freezing point of the distilled water- sugar solution can be determined by finding the temperature at which the mixture initially started to freeze. Unlike pure distilled water, the mixture results in a gradual linear decrease in temperature during freezing.



Discussion

Answer the following questions in complete sentences.

1. What is the least precise measurement in this experiment? How does this limit your significant digits?
2. What is the van't Hoff factor for your solute? Justify your answer.
3. List the the following aqueous solutions in order of INCREASING freezing point. Justify your answer. 0.1 M Na_3PO_4, 0.2M $C_6H_{12}O_6$, 0.1M $CaCl_2$, 0.2 M KBr
4. Why is it advantageous to choose a solvent that has a large value for K_f?
5. The following errors occurred when the above experiment was carried out. How would each affect the calculated molecular mass of the solute (too high, too low, no effect)? Explain your answers.
   a. The thermometer used actually read 1.4^{o}C too high throughout the experiment.

   b. Some of the solvent spilled before the solute was added.

   c. Some of the solute was spilled after it was weighted and before it was added to the solvent.

   d. Some of the solution was spilled after the solute and solvent were mixed but before the freezing point was determined.

In your introduction,

- Give a definition of colligative properties.
- Describe how freezing point depressions are calculated; include the relevant formula.
- Discuss the van't Hoff factor: How is it determined? What effect does it have on the freezing point?

In your conclusion, remember to restate your quantitative results and discuss experimental sources of error.

Sources:

Randall, Jack. *Advanced Chemistry with Vernier*, 2004 (Vernier Software and Technology).
Vonderbrink, Sally Ann. *Laboratory Experiments for Advanced Placement Chemistry*, 2001 (Flinn Scientific, Inc.)