

## Colligative Properties - Freezing Point Depression

**Suggested reading:** *Chang* text – pages 505 – 514

### Purpose

To observe freezing point depression of different solutions and calculate the molar mass of commercial antifreeze.

### Introduction

In winter, trucks dispense dirt and salt onto the roads and antifreeze is used in car radiators. By mixing another substance with water in either of these cases, the melting point of the mixture drops below the normal melting point of pure water, thus preventing the water from freezing.

When two different chemical substances are mixed together to form a homogeneous mixture, the resulting mixture is called a solution. The solvent determines the state of the mixture and is typically present in the highest quantity. Any other substances present are called solutes. Vinegar is a mixture of acetic acid in water, where water is the solvent and acetic acid is the solute.

When a non-volatile solute is dissolved in a solvent, physical properties of the solution are different from those of the components. Some of the physical properties affected include vapor pressure, boiling point, and freezing point. Solutions of non-volatile solutes have reduced vapor pressures and freezing points relative to pure solvent, as well as increased boiling points. The magnitude of these changes depends on the concentration of the solution:

$$\Delta T_f = k_f \cdot m \quad (1)$$

Where  $\Delta T_f$  is the observed change in the normal freezing point,  $K_f$  is the freezing-point depression constant (which is solvent-dependent), and  $m$  is the molality, or moles of solute per kilogram of solvent.

When the solute is a strong electrolyte, a modification must be made to **(1)**, since freezing point depression is also dependent on the number of particles the solute forms upon dissolving:

$$\Delta T_f = i \cdot k_f \cdot m \quad (2)$$

Where  $i$  (known as the Van't Hoff factor) is the maximum number of ions obtained from dissociation of the strong electrolyte. For example, the ideal Van't Hoff factor for ammonium chloride ( $\text{NH}_4\text{Cl}$ ) is  $i = 2$ , and for potassium sulfate ( $\text{K}_2\text{SO}_4$ )  $i = 3$ .

In this experiment, a mixture composed of rock salt and ice will be prepared at  $-10^\circ\text{C}$ . This mixture will then be used to determine the freezing point changes in aqueous solutions of table salt ( $\text{NaCl}$ ) and sugar ( $\text{C}_{12}\text{H}_{22}\text{O}_{11}$ ). In addition, the molar mass (g/mol) of automotive antifreeze will be calculated based on the observed freezing point depression. The molality ( $m$ ) of the unknown solution is calculated by equation 1 and can be related to molar mass (MM) by equation 3:

$$m = \frac{m(\text{antifreeze, g})}{\text{MM}(\text{antifreeze}) \times m(\text{water, kg})} \quad (3)$$

### Procedure

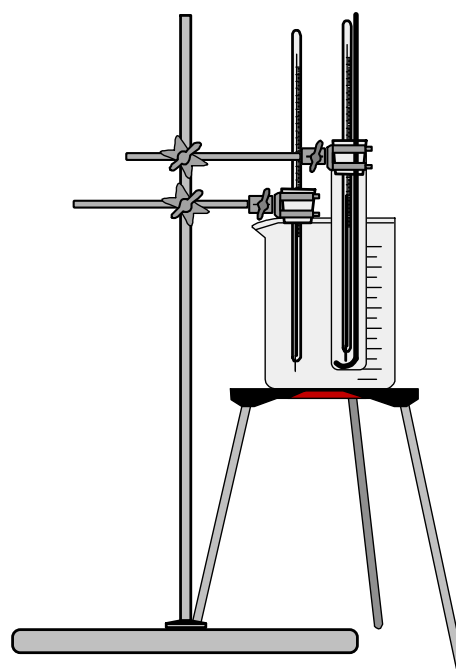
## Colligative Properties - Freezing Point Depression

### Part A: Preparing the Salt/Ice Mixture

- A1. A figure of the experimental setup is shown in Figure 1 below. To assemble, first obtain a 600- or 800-mL beaker, tripod or ring, wire mesh and ring stand, as well as a thermometer, one-hole split stopper and clamp.
- A2. Add enough ice to fill the beaker half full. Place the wire mesh on the tripod and the beaker on the wire mesh. Place the thermometer in the split stopper, and clamp the stopper to a ring stand, positioning the thermometer so it is immersed in the ice bath.
- A3. Add up to  $\frac{1}{2}$  inch of rock salt to the ice and mix well, being careful not to break the thermometer. **DO NOT USE THE THERMOMETER TO STIR THE MIXTURE!** Allow the temperature to become constant, and observe. If it is not below  $-10\text{ }^{\circ}\text{C}$ , add more rock salt and stir well. Continue to do this until the water bath is at or below the desired temperature. Liquid may need to be removed and more rock salt and ice added throughout the lab to maintain this temperature.

### Part B: Determining the Melting Point of Pure Water, Salt Solution and Sugar Solution

- B1. Obtain, clean and dry three large test tubes, stirrer, and thermometer and split two-hole stopper. Label the three test tubes *Water, Salt, and Sugar*.
- B2. Prepare a salt solution by adding  $\sim 1.0$  grams of NaCl (record exact mass on table) to the *Salt* test tube. Measure 10.0 mL of DI water in a graduated cylinder; weigh the filled cylinder. Add the water to the test tube and then weigh the empty cylinder. Mix until all the crystals dissolve.
- B3. Prepare a sugar solution by adding  $\sim 4.0$  grams of sugar (record exact mass on table) to 10.0 mL of DI water (weighing the water in the same manner). Mix until all the crystals dissolve.
- B4. Calculate the molality of the sugar and salt solutions based upon the masses recorded.
- B5. Add about 1 – 2 inches of DI water to the *Water* test tube. Use a clamp to suspend the test tube in the ice bath, making sure the solution is completely immersed in the bath.
- B6. Stopper the tube with the two-hole split stopper holding the stir rod and thermometer. Place the test tube in the ice/salt/water bath. Move the stirrer up and down continuously to agitate the water, pausing every 30 seconds to record the time and temperature. Continuous stirring is important to make accurate freezing point measurements. Continue reading the temperature until the water has frozen enough to make stirring difficult. *Note: Estimate and record temperatures to the nearest  $0.1\text{ }^{\circ}\text{C}$*
- B7. Repeat this measurement using the same sample of water for a total of two trials. Placing the test tube in a beaker of room temperature water will speed the thawing of the ice.
- B8. Repeat steps **B6** and **B7** using the salt and sugar solutions in place of the water.
- B9. Record the average observed freezing point of pure water, NaCl solution and sugar solution.



**Figure 1:** Experimental setup for freezing point determination.

## Colligative Properties - Freezing Point Depression

### Part C: Determining the Molar Mass of Commercial Automobile Antifreeze

- C1. Obtain ~10.0 mL of prepared aqueous antifreeze solution and record exact concentration from the bottle.
- C2. Freeze this solution as the solutions in part B, making sure to record temperatures every 30 seconds until a constant temperature is reached.
- C3. Allow the frozen water-antifreeze mixture to melt, and then repeat this process.

### Calculations:

1. Calculate the change in freezing point ( $\Delta T_f$ ) of the NaCl, sugar, and antifreeze solutions using the average observed freezing point of pure water as the normal freezing point of pure water.
2. Calculate the molalities of the NaCl and sugar solutions using the recorded masses of solute and solvent.
3. From the antifreeze freezing point data, calculate an experimental value of the molality of the antifreeze solution. Use this calculated molality to obtain an experimental molar mass (MM) of the antifreeze (show work on page 7).

### Disposal

If uncontaminated, please return any used antifreeze solution to the appropriately labeled container. If the sample has been contaminated, please notify the instructor so it can be appropriately disposed of as waste.

### Clean-Up

Wash all glassware with soap then rinse 3 times with tap water, and once with deionized water. Return all borrowed items to their original locations.

## Colligative Properties - Freezing Point Depression

**(This page intentionally left blank)**



## Colligative Properties - Freezing Point Depression

### Data Sheets

Name: \_\_\_\_\_ Lab Partner \_\_\_\_\_

#### Freezing Point of a Sugar Solution

Mass of Sugar Used: \_\_\_\_\_ g    Mass of H<sub>2</sub>O used: \_\_\_\_\_ g    Molality of Sugar solution: \_\_\_\_\_ m

Trial 1				Trial 2			
Time	Temp	Time	Temp	Time	Temp	Time	Temp

Average Freezing Point of Sugar Solution: \_\_\_\_\_  $\Delta T_f$  \_\_\_\_\_

#### Molar Mass of Commercial Antifreeze

Listed Concentration of Antifreeze Solution (from bottle): \_\_\_\_\_

Trial 1				Trial 2			
Time	Temp	Time	Temp	Time	Temp	Time	Temp

Average Freezing Point of Antifreeze solution: \_\_\_\_\_  $\Delta T_f$  \_\_\_\_\_

Calculated Molality: \_\_\_\_\_

## Colligative Properties - Freezing Point Depression

### Calculations:



## Colligative Properties - Freezing Point Depression Pre-lab Assignment

Name: \_\_\_\_\_

1. You are asked to prepare a salt/ice mixture at a temperature less than  $-10\text{ }^{\circ}\text{C}$  to use in performing sections B and C.
  - a. Why is it important that the mixture temperature is less than  $-10\text{ }^{\circ}\text{C}$ ?
  
  
  
  
  
  
  
  
  
  
  - b. Use your knowledge of freezing point depression to determine an approximate mass of sodium chloride needed to prepare a mixture containing 850.0 grams of ice slush at  $-10.0\text{ }^{\circ}\text{C}$ .
  
2. A solution is prepared by mixing 3.72 grams of an unknown non-electrolyte with 325.0 grams of chloroform. The freezing point of the mixture is  $-64.10\text{ }^{\circ}\text{C}$ , while the freezing point of pure chloroform is  $-63.50\text{ }^{\circ}\text{C}$ . Using a value of  $4.68\text{ }^{\circ}\text{C}/m$  as the  $k_f$  of chloroform, calculate the molar mass of the unknown.
  
  
  
  
  
  
  
  
  
  
3. An unknown alcohol is analyzed by freezing point depression. The unknown is either methanol ( $\text{CH}_3\text{OH}$ ), ethanol ( $\text{C}_2\text{H}_5\text{OH}$ ) or propanol, ( $\text{C}_3\text{H}_7\text{OH}$ ). A solution of 10.187 g of the unknown and 100. mL of water freezes at  $-4.2\text{ }^{\circ}\text{C}$ . What is the identity of the alcohol? Show a calculation to support your decision.