Molar Mass Determination by Freezing Point Depression

INTRODUCTION

Colligative properties of solutions depend upon the concentration of solute particles. The freezing points of water solutions are always lower than that of pure water. The change in freezing point caused by the presence of a solute dissolved in water can be calculated from the equation,

$$\Delta T = T_{fp}\,(\text{solution}) - T_{fp}\,(\text{solvent}) = (K_{fp})(m)(i)$$

where K_{fp} is the molal freezing point depression constant (-1.86ºC/m for water), m is the molality of the solution, and i is the number of particles produced per formula unit.

molality (m) = moles of solute/kg solvent

In the first part of this experiment, you will determine the freezing points of various solutions after adding solid solutes to water. In the second part, freezing point depression is used to determine the molar mass of an unknown molecular liquid solute.

EXPERIMENTAL PROCEDURE

Safety Precautions: Wear safety goggles at all times while in the laboratory.

A. <u>Determination of Freezing Point of Solutions</u>:

<u>Preparation of Ice Bath</u>

1. Fill the coffee-cup 3/4 full with crushed ice.
2. Cover the ice with about a 1/4 inch layer of Rock Salt.
3. Stir this ice-salt mixture with a stirring rod and make sure the temperature drops to at least -10°C.

<u>Preparation of Samples:</u>

1. Solvent: Fill a medium sized test tube with 1/3 full of DI-water.

2. NaCl solution: Weigh an empty beaker. Place about 25 mL DI-water into the beaker. Record the mass of water. Add about 1.4 g of sodium chloride in this beaker. Record the mass of sodium chloride. Stir the solution until all crystals dissolve. Fill a medium sized test tube with 1/3 full of this sodium chloride solution.

3. Sucrose solution: Weigh an empty beaker. Place about 25 mL DI-water into the beaker. Record the mass of water. Add about 4.3 g of sucrose, $C_{12}H_{22}O_{11}$, in this beaker. Record the mass of sucrose. Stir the solution until all crystals dissolve. Fill a medium sized test tube with 1/3 full of this sucrose solution.

<u>Freezing Point Measurements:</u>

1. Place the test tube containing DI-water (or tested solution) in the ice bath.
2. Stir the solution in the test tube gently with a stirring rod while keeping track of the temperature. When the first ice crystals appear on the inside wall of the test tube, record the temperature.
3. Repeat steps 1-3 with the prepared solutions to determine their respective freezing points.

B. Molar Mass Determination by Freezing Point Depression:

Preparation of Ice Bath (See Part A).

Preparation of Samples:

1. Solvent: Fill a medium sized test tube with 1/3 full of DI-water.

2. Solution: Weigh an empty and dry beaker. Place about 25 mL DI-water into the beaker. Record the mass of water. Add about 2 -3 g of unknown liquid in this beaker. Record the mass of the liquid added. Stir to mix the solution. Fill a medium sized test tube with 1/3 full of this solution.

Freezing Point Measurements: (See part A)

Clean-Up. Dispose of unknown liquid solution (part B) into proper waste container. The solutions of sodium chloride and sucrose (part A) as well as the ice bath can be poured down the drain. Clean all glassware that was used, and wipe the lab counter with WET paper towel before leaving the laboratory.

Name ____________________ **Date** ______ **Grade**_____

PRE-LAB QUESTIONS

MUST be completed before an experiment is started. The COPY pages will be collected as you enter the lab.

Q1. What types of intermolecular forces are present in a molecular solid such as lauric acid? Describe what is happening with regard to intermolecular forces as a molecular liquid freezes.

Q2. If you were able to choose a solvent for this experiment from the list below, which would you choose? Justify your answer.

- Acetic Acid CH_3COOH K_f = 3.90 °C•kg/mol
- Benzene C_6H_6 K_f = 5.12 °C•kg/mol
- tert-Butanol C_4H_9OH K_f = 9.10 °C•kg/mol
- Cyclohexane C_6H_{12} K_f = 20.00 °C•kg/mol

Q3. What is the equation for calculating molality? Why do we use molality rather than molarity as our concentration unit for this experiment?

Q4. Use the equation above along with the freezing-point depression equation to derive an expression for calculating the molar mass of a solute.

Q5. The following data were obtained in an experiment designed to determine the molar mass of a solute by freezing-point depression. The K_f of *para*-dichlorobenzene is 7.1 °C•kg/mol

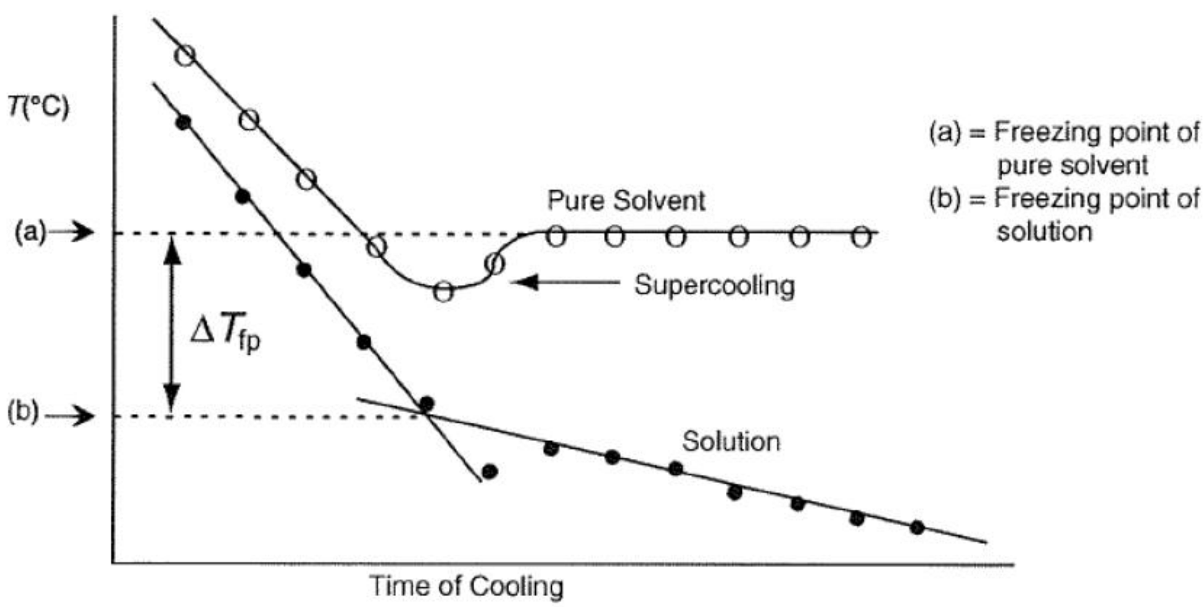
Mass of *para*-dichlorobenzene (g)	24.80 g
Mass of unknown solute (g)	2.04 g
Freezing temperature of pure *para*-dichlorobenzene (°C)	53.02 °C
Freezing point of the solution (°C)	50.78 °C

(a) Calculate the freezing-point depression, ΔT_f of the solution.

(b) Calculate the molar mass of the unknown substance.

Q6. Examine the graph below. What laboratory technique best prevents supercooling?

Temperature vs. Cooling Time for Solvent and Solution



Molar Mass Determination by Freezing Point Depression

Name ______________________________ Date ________

A. Determination of Freezing Points of Solutions:

1. NaCl solution:

	Trial 1	**Trial 1**
Mass of water	_________ g	__________ g
Mass of NaCl (s)	_________ g	__________ g
Molality of solution	__________ m	__________ m
Freezing point of water	__________ ^{0}C	__________ ^{0}C
Freezing point of solution	__________ ^{0}C	__________ ^{0}C
Actual $\Delta T_{fp} = T_{fp}$ (solution) – T_{fp} (water)	__________ ^{0}C	__________ ^{0}C
Theoretical $\Delta T_{fp} = (K_{fp})(m)(i)$	__________ ^{0}C	__________ ^{0}C
$\%Error = \left\| \frac{Actual\Delta T_{fp} - Theoretical\Delta T_{fp}}{Theoretical\Delta T_{fp}} \right\| x100\%$	___________ %	___________ %

Average % Error ___________ %

2. Sucrose solution:

	Trial 1	Trial 2
Mass of water	____________ g	____________ g
Mass of sucrose (s)	____________ g	____________ g
Molality of solution	__________ m	__________ m
Freezing point of water	__________ ^{0}C	__________ ^{0}C
Freezing point of solution	__________ ^{0}C	__________ ^{0}C
Actual $\Delta T_{fp} = T_{fp}$ (solution) – T_{fp} (solvent)	__________ ^{0}C	__________ ^{0}C
Theoretical $\Delta T_{fp} = (K_{fp})(m)(i)$	__________ ^{0}C	__________ ^{0}C
$\%Error = \left\lvert \frac{Actual\Delta T_{fp} - Theoretical\Delta T_{fp}}{Theoretical\Delta T_{fp}} \right\rvert x100\%$	___________ %	___________ %

Average % Error ______________ %

B. Molar Mass Determination by Freezing Point Depression:

	Trial 1	**Trial 2**
Mass of water	____________ g	____________ g
Mass of liquid solute	____________ g	____________ g
Freezing point of water	___________ ^{0}C	__________ ^{0}C
Freezing point of solution	___________ ^{0}C	__________ ^{0}C
Molality of solution $\Delta T_{fp} = (K_{fp})(m)(i)$	_______________ mole solute/kg solvent	_______________ mole solute/kg solvent
Mass of solute per kg solvent	______________ g solute/kg solvent	______________ g solute/kg solvent
Molar mass of solute	__________ g/mol	__________ g/mol

Average molar mass of solute __________ g/mol

Unknown #: __________________

Post-Lab Questions and Exercises
(All questions must be answered during the lab and submitted with your lab report at the end of the lab period).

Q1. A student determines the molar mass of a molecular compound by the method used in this experiment. She found that the equilibrium temperature of a mixture of ice and water was 1.0 ^{0}C. When she added 11.1 g of her sample to the mixture, the temperature, after thorough stirring, fell to -3.0 ^{0}C, and the mass of the solution was 90.4 g. Calculate:

a) The freezing point depression of the solution

b) Molality of the solution

c) Mass in grams of solute in the solution

d) Mass in grams of water in the solution

e) Mass in grams of solute in a solution containing 1 kg of water

f) Molar mass of the solute.

Q2. Calculate molality (*m*), in mol/kg, using the formula $\Delta T_f = K_f \times m \times i$. The K_f value for lauric acid is 3.9°C•kg/mol and since lauric acid is a molecular solid, *i* is approximately equal to 1.

Q3. Calculate moles of benzoic acid solute, using the molality and the mass (in kg) of lauric acid solvent.

Q4. Explain why the pure solvent shows a level horizontal curve as solidification occurs, but the curve for the solution slopes downward slightly.

Q5. A student spills some of the solvent before the solute was added. What effect does this error have on the calculated molar mass of the solute? Mathematically justify your answer.

Q6. A different student spills some of the solution before the freezing-point was determined. What effect does this error have on the calculated molar mass of the solution? Justify your answer.