Molar Mass from Freezing Point Depression

Introduction:

When a pure substance freezes, the individual particles (molecules, atoms, ions) must organize themselves such that their intermolecular forces prevent them from flowing. If an impurity is introduced into this pure substance, the intermolecular forces that allow the substance to freeze are disrupted meaning that more energy must be removed from the system before the particles can organize. This means that a solution will always freeze at a lower temperature than the pure solvent. It is important to note that the amount that the freezing point is lowered does not depend upon the identity of the solute, it's just dependent upon the number of solute particles in the solution. Properties which depend only upon the amount of solute and not its identity are called colligative properties, and they include freezing point depression, boiling point elevation and others. The concentration unit typically used to calculate colligative properties is molality because the molality of a solution is independent of the temperature. Molality has units similar to molarity, but rather than $^{\text{mols of solute}}/_{\text{L of solution}}$ (molarity, M), molality is defined as $^{\text{mols of solute}}/_{\text{kg of solvent}}$ and is abbreviated with a lower-case "m".

Safety Concerns:

Cyclohexane is extremely flammable. Do not have any flames in the laboratory.

Experimental Procedure:

I. Freezing Point of Pure Cyclohexane

Obtain an 18x100mm test tube and place a small Teflon-coated stir bar in the bottom of the tube. Pipette 5.00 mL (±0.01 mL) of cyclohexane into the test tube. Clamp the tube on the ring stand inside a 400-mL beaker. Add a stir bar and clamp the temperature probe in the tube. The probe should not touch the wall of the tube. Once the test tube and temperature probe are positioned, slide the stir plate out from beneath the apparatus and remove the beaker. Prepare an ice-water bath in the beaker (mostly ice, just enough water to make the bottom half look wet). Set up LoggerPro to record temperature vs. time. When you are ready to begin a run, slide the ice-water bath onto the test tube and position the stir plate. Collect temperature vs. time data until the sample is frozen and record the freezing point. Remove the ice-water bath, melt the cyclohexane sample and repeat until you are confident in your results. Print one representative cooling curve for cyclohexane.

Q: Why should the temperature probe NOT be allowed to touch the side of the test tube? Why are you measuring the freezing point of cyclohexane and not simply looking it up? Compare your freezing point to others in the class and to published/accepted values.

II. Freezing Point Depression of a Cyclohexane Solution

A. Weigh approximately 0.080-0.090g of benzophenone ($C_6H_5COC_6H_5$) to the nearest thousandth of a gram (±0.001g) and record the mass. Remove the temperature probe from the test tube being careful not to lose any liquid from the tube and add the sample of benzophenone to the cyclohexane. Allow the benzophenone to dissolve by stirring and warming the solution if necessary. Reposition the probe and perform the same procedure as in part I to determine the freezing/melting point of the resulting solution. Print one representative cooling curve for this solution.

Q: Did the freezing point of the solution differ from the freezing point of the pure solvent? Explain your observation on a molecular level.

B. Calculate the freezing point depression constant, k_{fpd}, for cyclohexane. ($\Delta T_{fp} = k_{fpd} \cdot m \cdot i$) Benzophenone is a *molecular* solute in cyclohexane; therefore, each benzophenone molecule yields one solute particle so the value of "i" is 1.

III. Determination of the Molar Mass of an Unknown

A. Empty the cyclohexane solution from part II into the appropriately labeled waste container in the hood. Rinse the tube with a small amount of solvent provided in a wash bottle. Dry the tube, clean the magnetic stir bar and the probe. Dispense a fresh 5.00-mL aliquot of cyclohexane into the tube. Bottles containing unknowns will be placed by the balances with specified ranges of masses to be used for each unknown. Weigh out (to ±0.001 g) the appropriate amount of the unknown assigned to you. Be sure to record your unknown number in your lab book and to communicate it in your lab report or hand-in. Please leave the balance pan and the balance area clean for other students and for yourself. Measure temperature vs. time data as above to determine the freezing point of this solution. Print one representative cooling curve for this solution.

Q: How can you determine the concentration (molality) of this solution if you do not know the identity of the solute? {NOTE: You may assume that all the unknowns are molecular solutes.}

In your lab report be sure to include the following.

- Graphs of the three cooling curves with the freezing point temperature clearly labeled on each one.
- All the calculations called for in part IIB and IIIC.
- Unknown number and the molar mass you determined for your unknown.

Calculation Notes:

Each part of this experiment is using the same equation, the only thing that changes is the unknown variable. In the first part, we need to determine the freezing point of pure cyclohexane so we can determine how much the freezing point temperature changes when a solute is added. In the second part, we are using a known solute so we can make a solution of known concentration. With that solution of known concentration, we can measure the change in freezing point temperature and use this data to calculate the freezing point depression constant (k_{fpd}) for cyclohexane. Once we know the value of the freezing point depression constant for cyclohexane, we can use it to determine the molar mass of an unknown molecular solute.

$$\Delta T_{fp} = \left(T_{fp,puresolvent} - T_{fp,solution}\right) = \left(k_{fpd}\right)(m)(n) = \left(k_{fpd}\right)\left(\frac{\left(\frac{\text{grams of solute}}{\text{molar mass of solute}}\right)}{\text{kg of cyclohexane solvent}}\right)(n)$$

Part I: Determine the freezing point of pure cyclohexane (→ $T_{fp,puresolvent}$)

Part II: Determine the freezing point depression constant for pure cyclohexane (→ k_{fpd})

Part III: Determine the molar mass of an unknown molecular solute (→ molar mass of solute)