Formula Weight by Freezing Point Depression

Introduction

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

\[ \Delta T = i \cdot K_f \cdot m \]

where \( \Delta T \) is the freezing point depression, \( K_f \) is the freezing point depression constant, specific for a given solvent (3.90 °C/m for lauric acid in this experiment), \( m \) is the molality of the solution and \( i \) is the van’t Hoff factor, which represents the integer number of particles formed by the solute when in solution. Molality \( (m) \) is used because it is independent of the volume changes that can occur with variations in temperature, unlike molarity \( (M) \).

\[ m = \frac{\text{moles solute}}{\text{kg of solvent}} \]

In this experiment, the freezing temperature of the pure solvent, lauric acid, CH\(_3\)(CH\(_2\))\(_{10}\)COOH is found first. Next the freezing point of a solution prepared from a mixture of an unknown organic acid \((i = 1)\) and lauric acid is measured. By measuring the masses of the unknown organic acid and lauric acid in the mixture and finding the freezing point depression, \( \Delta T \), the equations above can be used to find the formula weight of the unknown acid.

Look up the melting point (freezing point) of pure lauric acid (also called "dodecanoic acid").

Part I: Freezing Temperature of Pure Lauric Acid

1. Prepare a water bath by adding about 300 mL of distilled water to a 400 mL beaker. Heat the water bath to 70-80 °C on a hot plate and adjust the setting to maintain it.

2. Weigh an empty test tube and record the mass to 0.1 mg.

3. Carefully, use a spatula to directly fill the test tube about 2/3 full with solid lauric acid. Weigh the test tube with the lauric acid and record the mass to 0.1 mg. Clamp the test tube into the hot water bath.
3. Once the lauric acid begins to melt, insert a thermometer and stir gently until it is fully melted.

4. When the lauric acid has been melted for at least 2 minutes, remove the water bath.

5. Allow the liquid to reach 60 – 70 °C, then record the temperature every 30 seconds, gently mixing occasionally, being very careful not to break the thermometer.

6. When the sample begins to crystallize note the temperature in your notebook.

7. Continue recording the temperature every 30 seconds until the lauric acid is mostly solidified. As crystallization of the lauric acid occurs, the temperature will be nearly constant. This temperature is the freezing point of the pure solvent (lauric acid).

8. Return the hot water bath to re-melt the lauric acid and repeat from step 4 once more.

Part II. Freezing Temperature of a Solution of Unknown Organic Acid and Lauric Acid

1. Handling with a Kimwipe, weigh the vial marked "unknown acid".

2. Carefully add the contents of the vial to the test tube of melted lauric acid.

3. Weigh the empty vial. The difference in mass is the amount of unknown added to the lauric acid.

4. Gently stir the solution with the thermometer until it is well mixed.

5. Remove the hot water bath. When the temperature reaches 55 – 65 °C record the temperature of the solution every 30 seconds. Gently mix the lauric acid solution occasionally, being very careful not to break the thermometer.

6. When the mixture begins to crystallize, note the temperature in your notebook.

7. As crystallization of the lauric acid solution occurs, the sample will cool at a much slower rate and may not remain constant.

8. Return the hot water bath to re-melt the lauric acid and repeat from step 4 once more.

Question

1. Is the freezing point the same as the melting point for pure lauric acid? Why?

2. When 2.04 g of a substance is dissolved in 7.84 g of solvent, the solution freezes at 10.8 °C. The pure solvent has a freezing point of 14.3 °C. The \( K_f \) for the solvent is 2.80 °C/m. Calculate the formula weight of the substance.
Data Treatment and Discussion

1. Plot the data (temperature versus time) for the pure lauric acid and the solution. Determine the freezing points by extrapolation of the linear portions of the plots before and after crystallization begins. Figures I and II illustrate the procedure on unrelated data.

**Figure I.** Freezing curve of a pure substance showing two linear portions extrapolated to find the melting point at the intersection (79.8 °C).

**Figure II.** Freezing curve of a solution showing two linear portions extrapolated to find the melting point at the intersection (75.4 °C). Note that the temperature after crystallization (after 100 s) is not constant (as it is in Figure I.)
2. Determine $\Delta T$ ($T_1 - T_2$), where $T_1$ is the melting point of pure lauric acid and $T_2$ is the freezing point of the and lauric acid/unknown solution.

3. Calculate molality ($m$), of the unknown solution, assuming $K_f = 3.90 \text{ } ^\circ\text{C}/m$ and $i = 1$.

4. Calculate moles of unknown acid solute using the molality from above and the mass (in kg) of lauric acid solvent.

5. Calculate the experimental formula weight of the unknown organic acid. Use the mass of unknown acid used in the experiment and the moles of unknown acid from #3.

**Conclusion**

Give the calculated formula weight of the unknown acid. Assuming that part of the structure of the unknown acid has a $-\text{COOH}$ group and the remainder contains just C and H, suggest a molecular formula. Determine the percent error in your analysis from the suggested formula.

Why is the graph of the pure lauric acid different from the graph of the mixture of acids?