Colligative Properties and Freezing-Point Depression

Solution chemistry is an important topic in our understanding of general chemistry; mixtures of chemicals take on predictable behaviors based upon fundamental principles that can be seen in both laboratory settings as well as the real world around us. The colligative properties can be readily explored in a laboratory; this week we examine the phenomenon of freezing-point (melting-point) depression.

The four colligative properties are freezing-point depression, boiling-point elevation, osmotic pressure, and vapor-pressure lowering. Each of these properties can be predicted \textit{a priori} given the solute concentration and the physical properties of the pure solvent. In our case, the freezing point depression can easily be measured by knowing three facts: the mass of the solvent, the mass of the added solute, and the molal freezing-point depression constant (sometimes called the “cryoscopic constant”) for the specific solvent.

We will use the following formula: \[ \Delta T = K_f \cdot m \cdot i \]

Where \( K_f \) = molal freezing-point depression constant for the specific solvent
\[ m = \text{molality (moles solute/kg solvent)} \]
\[ i = \text{van't Hoff factor (accounts for the ionizability of the solute molecules)} \]

The solvent will be dodecanoic acid (also known as lauric acid): \( \text{C}_{12}\text{H}_{24}\text{O}_2 \). \( K_f \) for dodecanoic acid is 3.90 °C/m.

Our possible unknown solutes are benzoic acid (\( M = 122 \text{ g/mol} \)), salicylic acid (\( M = 139 \text{ g/mol} \)), adipic acid (\( M = 167 \text{ g/mol} \)), camphor (\( M = 152 \text{ g/mol} \)), and cyclohexanone (\( M = 98 \text{ g/mol} \)).

The freezing point of the pure solvent will be found first. Next, the freezing point of the solution formed by dissolving your unknown in dodecanoic acid will be measured. By knowing the masses of the unknown solute and the dodecanoic acid and measuring the freezing-point depression, the molality of the solution and thus the molar mass of the unknown can be calculated.
Equipment
   1 20-mL test tube per group
   1 250-mL beaker per group
   1 hot water (70-80 °C) bath (600-mL beaker and hot plate) per group
   1 warm water (approximately 20 °C) bath (600-mL beaker) per group
   1 digital thermometer per group (use Logger Pro)
copper stirring wire

Procedure
Part 1 – Determining the freezing point of pure dodecanoic acid

01. Place a test tube into a 250 mL beaker. (The beaker just keeps the test tube from falling over during weighing.)
02. Tare the beaker and test tube.
03. Place a mass of between 10 and 12 grams of dodecanoic acid into the test tube and record its exact mass.
04. Place the test tube with the dodecanoic acid into the warm water bath and heat until all of the dodecanoic acid has melted.
05. Remove the test tube with the dodecanoic acid from the hot water bath and place it into the cooler bath.
06. Place the temperature probe into the test tube with the now melted dodecanoic acid.
07. When the temperature reaches 60 °C begin recording the temperature using Logger Pro.
08. To stir, use the copper wire around the probe. Stir gently.
09. Continue recording the temperature until the temperature of the dodecanoic acid has dropped below 38 °C.
10. Repeat the above steps 4-9 one time so that you will have two values for the freezing point of dodecanoic acid.
Part 2 – Determining the freezing point of the unknown and dodecanoic acid solution

11. Use the same sample and equipment as you did in the previous part.
12. Using a weighing boat, measure out between 2.0 and 3.0 grams (to at least 0.01 g) of unknown. If your unknown is a liquid, look up and record the density (from the unknown bottle AND the volume of unknown used to determine the mass of the unknown. Make sure that you record the letter or number of the unknown in your lab notebook
13. Place the test tube continuing the dodecanoic acid sample from the previous trial in the hot water bath.
14. When the dodecanoic acid has all melted, add the unknown.
15. Using a stirring rod, mix in the unknown. Thoroughly, but gently stir the mixture until the unknown is dissolved in the dodecanoic acid.
16. Remove the test tube with the dodecanoic acid from the warm water bath and place it into the cooler bath.
17. When the temperature reaches 60 °C begin recording the temperature using Logger Pro.
18. To stir, use the copper wire around the probe. Stir gently.
19. Continue recording the temperature until the temperature has dropped below 28 °C. Remelt your solution by placing the test tube in the warm water bath, then repeat steps 16 – 19 one time so that you will have two values for the freezing point of the dodecanoic acid solution.

Data Analysis

Your plotted data should yield cooling curves that look similar to those in the Figure below.

![Diagram showing cooling curves](image)

From Part 1, take the average of the two freezing point experiments to get the freezing point for dodecanoic.
From Part 2, take the average of the two freezing point experiments to get the freezing point for the dodecanoic acid solution and determine $\Delta T$, the magnitude of the freezing-point depression (a positive number) for the solution of the unknown solute and the dodecanoic acid.

Applying the formula $\Delta T = K_f \times m \times i$ and dividing, $\frac{\Delta T}{K_f} = M$ (the van't Hoff factor $i$ is equal to 1 for these compound because they are nonelectrolytes).

Knowing that molality is equal to moles of solute per kilogram of solvent, solve for the molecular weight ($M$) of the unknown and thus determine the identity of the unknown.

In your lab report, describe the possible sources of error in this experiment, indicate which of those error sources is most significant, and indicate how you might go about improving your results. Are you able to unambiguously identify your unknown? Why or why not?