Lab 11.5
Molar Mass by Freezing Point Depression

BACKGROUND

The presence of a nonvolatile solute in solvent alters the physical properties of the solvent by interfering with the intermolecular forces between solvent particles. This interference lowers the vapor pressure of the solvent, thereby affecting its freezing and boiling points.

The boiling point of the solution will be higher for the solution than the pure solvent. The elevation in boiling point is directly proportional to the molal concentration of the solute by the formula, $\Delta T_b = k_b m i$, where k_b is a constant specific to the solvent and “i” represents the van’t Hoff factor (a multiplier that represents the number of particles produced from the dissolution of the soute). ΔT_b represents the increase in boiling point and must be <u>added</u> to the normal boiling point of the solvent to find the boiling point of the solution.

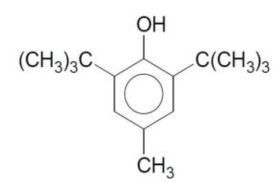
The freezing point of the solution will be lower for the solution than the pure solvent. The decrease in freezing point is also directly proportional to the molal concentration of the solute by the formula, $\Delta T_f = k_f m i$, where k_f is a constant specific to the solvent. ΔT_f represents the decrease in freezing point and must be <u>subtracted</u> from the normal boiling point of the solvent to find the freezing point of the solution.

The molar mass of an unknown solute dissolved in solution may be found by examining the change in the freezing point or boiling point caused by the presence of solute. If the constant (k_f or k_b) is known, the molality of the solution may be calculated which allows the number of moles of solute to be determined.

In this experiment, you will determine the freezing point of a pure solvent; use a known solute to determine the k_f value of the solvent; then use that k_f value to determine the molar mass of an unknown solute. The substances are all molecular and no dissociation will occur (i = 1).

The freezing point of BHT is approximately 70°C. Figure 1 shows the cooling curves obtained for both the pure solvent and for the solution. Notice that super-cooling occurs in both the solvent and the solution. When supercoiling occurs, the temperature falls below the freezing point until the first crystal forms. The temperature then rises and either stays at freezing point, or slowly falls as the solution freezes. The freezing point (T_f) of the solution is extrapolated from the graph.

Butylated hydroxytoluene (BHT) is a nonpolar substance frequently used as an antioxidant in foods. The IUPAC name for BHT is 2,6-di-*tert*-butyl-4-methylphenol, and has the structural formula:



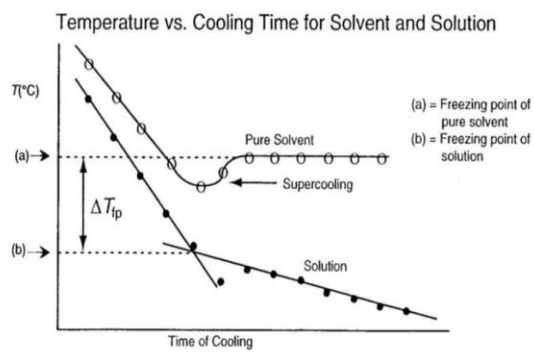


Figure 1. Freezing Point Graph for Pure Solvent and for Solution

Safety

- BHT is moderately toxic by ingestion and inhalation, and is a body tissue irritant.
- Cetyl alcohol, and unknown solid are slightly toxic by ingestion and are body tissue irritants.
- Follow open flame and heating precautions.
- Goggles and aprons must be worn.

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AP Chemistry

I. PURPOSE

To determine the molar mass of an unknown substance by measuring the freezing point depression of a solution of the unknown with BHT.

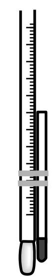
II. MATERIALS

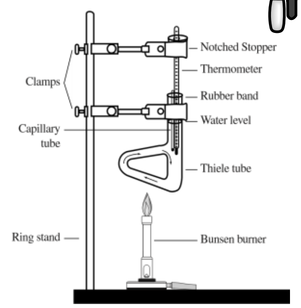
1. BHT
2. Cetyl alcohol
3. Unknown substance
4. Mortar and pestle
5. Capillary tubes
6. Thiele melting point tube
7. Spirit thermometer
8. Thermometer clamp apparatus
9. Analytical balance
10. Ring stand
11. Bunsen burner

III. PROCEDURES

<u>Part A – Melting Point of Pure BHT</u>

1. Pulverize 0.50 g of BHT into a fine powder using a mortar and pestle.
2. Pack the BHT in a capillary tube to a depth of about 2-3 mm (*Do not overpack the tube*.) by repeatedly pushing the open end into the pulverized sample. Pack it into the closed end by tapping the bottom of the tube on the desktop.
3. Attach the capillary tube to a thermometer with a rubber band as shown at right. The bottom of the capillary tube should be at the middle of the thermometer bulb.
4. Fill the Thiele tube with water to about 1-2 cm above the top flow point. Attach the Thiele tube to the utility stand using a utility clamp. Make sure it is at a correct height for heating with the Bunsen burner as shown at right.
5. Place a split stopper around the thermometer and attach it to the utility stand using the utility clamp. Hang the capillary tube/thermometer with the bulb of the thermometer at the top of the bow.
6. Heat the Thiele tube with the burner located near the end of the bow. The water bath may be heated rapidly in the beginning, but as the temperature approaches 60°C the water should be heated more slowly in order to get an accurate temperature reading of the melting point.
7. Record the temperature at which the BHT melts (the white powder will turn to a colorless liquid) in the Part A Data Table.





<u>Part B – Determining the K_f of BHT</u>

1. Weigh out 0.50 g of BHT. Record the exact mass in the Data Table.
2. Weigh out 0.10 g of cetyl alcohol and record the exact mass in the Data Table.
3. Combine the BHT and cetyl alcohol in the mortar and pestle. Grind and mix them together thoroughly, then gather in a small pile.
4. Repeat steps A.2 – A.7 with the BHT and cetyl alcohol mixture.

<u>Part C – Determining the Molar Mass of an Unknown Solid</u>

1. Weigh out 0.50 g of BHT. Record the exact mass in the Data Table.
2. Weigh out 0.10 g of the unknown and record the exact mass in the Data Table.
3. Combine the BHT and unknown in the mortar and pestle. Grind and mix them together thoroughly, then gather in a small pile.
4. Repeat steps A.2 – A.7 with the BHT and unknown solid.

IV. PRE-LAB QUESTIONS

1. Rearrange the molar mass equation below and substitute it into the molality equation for the "*mol solute*" term.

$$\text{molality } (m) = \frac{\text{mol solute}}{\text{kg solvent}} \qquad \text{molar mass } (MM) = \frac{\text{g solute}}{\text{mol solute}}$$

2. Freezing point depression is calculated by: $\Delta T_f = k_f \cdot m$. Substitute the equation for Question 1 for molality (m) and solve the equation for molar mass (MM).
3. What information will you need to obtain in lab to determine the molar mass of your unknown?
4. BHT has the formula $((CH_3)_3C)_2CH_3C_6H_2OH$ and cetyl alcohol has the formula $CH_3(CH_2)_{15}OH$. What type of intermolecular forces are present?

(Over)

Lab 13.6
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V. DATA & CALCULATIONS

A. DATA

	Mass of BHT (g)	Mass of Solute (g)	Melting Point (ºC)
Part A (BHT only)			
Part B (BHT & cetyl alcohol)			
Part C (BHT & unknown)			

B. CALCULATIONS

1. Calculate the freezing point depression (ΔT_f) of the BHT and cetyl alcohol mixture.
2. Calculate the molality of the BHT and cetyl alcohol mixture.
3. Using the information from calculations 1 & 2, find the freezing point depression constant (k_f) of BHT.
4. Using the derived equation from the pre-lab, determine the molar mass of the unknown substance.
5. Obtain the accepted value, and calculate your percent error for this lab.

VI. QUESTIONS & DISCUSSION OF ERROR

A. QUESTIONS

1. Explain why the freezing point of BHT is depressed.
2. What is the polarity of the unknown substance? Explain.
3. How would the freezing point of a solution of NaCl and BHT, with exactly the same molality, compare to the freezing point of the cetyl alcohol and BHT solution?
4. Suppose you find out that the actual molar mass of your unknown solid is exactly three times larger than the value you determined experimentally. What could you conclude about the nature of your unknown solid and the assumptions you made in your calculations in such a case? Explain.

B. DISCUSSION OF ERROR

VII. CONCLUSION