Purpose
The purpose of this experiment is to determine the molar mass of an unknown substance by measuring the freezing point depression of a solution of the unknown with BHT.

Background
There are a number of ways of determining the molar mass of a substance. One of the simplest involves finding the change in the freezing point of a solvent when an unknown substance is dissolved into it. The change in freezing point is directly proportional to the molality of the solution. This change in colligative property depends on the number of dissolved particles in solution, not the type of particle.

The solvent used in this experiment is a nonpolar substance with common name butylated hyroxytoluene (BHT). It is 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:

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 supercooling occurs, the temperature falls below the freezing point until the first crystal forms. The temperature then rises up 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.

![Figure 1. Freezing Point Graph for Pure Solvent and for Solution](image-url)
Pre-Lab Questions

1. The molality \((m)\) of a solution is calculated by: 
   \[
   m = \frac{\text{mol solute}}{\text{kg solvent}}
   \]

   Molar mass (MM) of solute is defined as: 
   \[
   MM = \frac{\text{g solute}}{\text{mol solute}}
   \]

   Rearrange the molar mass equation so that it can be substituted into the molality equation for the mol of solute.

2. Freezing point depression is calculated by: 
   \[
   \Delta T_f = k_f \cdot m
   \]

   Substitute your 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 in order to determine the molar mass of your unknown?

4. The following data was obtained for an unknown solute and \textit{para}-dichlorobenzene solvent.

   | \(K_f\) \textit{para}-dichlorobenzene | \[
   \begin{array}{c}
   7.1 \frac{^\circ C}{m}
   \end{array}
   |
   | \text{Freezing Point } \textit{para}-dichlorobenzene | 53.02 °C |
   | \text{Mass } \textit{para}-dichlorobenzene | 24.80 g |
   | \text{Mass of Unknown Solute} | 2.04 g |
   | \text{Freezing Point Solution} | 50.78 °C |

   a. What is the freezing point depression, \(\Delta T_f\)?

   b. What is the molar mass of the unknown?
Materials

**Equipment**
- Balance
- Weighing Boats
- Mortar and Pestle
- 3 Capillary Tubes
- Bunsen Burner
- Small Rubber Band
- Thermometer
- Rubber Stopper
- Test-Tube Clamp
- Ring Stand
- Beaker, 250-mL
- Hot Plate
- Magnetic Stirrer

**Chemicals**
- BHT, 1.5 g
- Cetyl Alcohol, 0.1 g
- Unknown Solid, 0.1 g
- Water, Tap (Water Bath)

**Safety Precautions**

- The BHT, 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. Hot glass looks exactly like cold glass.

- Eye safety and clothing precaution.

- Wash hands thoroughly with soap and water before leaving the laboratory.

**Procedure**

**Part 1: Preparing the Capillary Tubes**

1. Light a Bunsen burner and adjust the flame so it is strong with a bright blue cone in the center.
2. Place the end of the capillary tube in the flame and rotate until the end is melted and sealed. Set on the table to cool completely.
3. Repeat with the other two capillary tubes.

**Part 2: Melting Point of the Pure BHT**

4. Label a weighing boat as BHT. Zero it on the balance and obtain 0.50 g of BHT.
5. Transfer the BHT into the mortar and pestle and grind it into a fine powder. Push together into a small pile.
6. Pack the BHT into the capillary tube to a depth of about 1 cm. This can be done by pushing the open end of the tube into the pile of BHT, then turning it over and gently tapping it on the table.
7. Attach the capillary tube to the thermometer using a rubber band as shown.
8. Use a universal clamp and slit rubber stopper to fasten the thermometer to the ring stand. (See setup in front of room.)
9. Immerse the bottom of the capillary tube and thermometer in a beaker of water with the magnetic stirrer.

10. Heat gently, using the magnetic stirrer setting to evenly distribute the water bath. When the temperature of the water approaches 60°C, turn down the heat and observe closely.

11. Record the temperature at which the BHT melts (the white powder will become clear). Record in the Data Table.

**Part 3: Determine the $K_f$ of BHT with Cetyl Alcohol**

12. Weigh out another 0.50 g of BHT. Record the EXACT mass in the Data Table.

13. Label a weighing boat as cetyl alcohol. Weight out 0.10 g of cetyl alcohol and record the EXACT mass in the Data Table.

14. Combine the BHT and cetyl alcohol in the mortar and pestle. Grind and mix them together thoroughly, then gather in a small pile.

15. Repeat steps 6-11 with the BHT and cetyl alcohol mixture.

**Part 4: Determine the Molar Mass of an Unknown Solid**

16. Weigh out another 0.50 g of BHT. Record the EXACT mass in the Data Table.

17. Label a weighing boat as unknown. Weight out 0.10 g of the unknown and record the EXACT mass in the Data Table.

18. Combine the BHT and unknown in the mortar and pestle. Grind and mix them together, then gather in a small pile.

19. Repeat steps 6-11 with the BHT and unknown mixture.

**Cleanup**

20. Capillary tubes may be disposed in the broken glass containers.

21. Weighing boats go in the garbage.

22. Wash, dry, and put away all equipment. Wash down lab tables. Wash and dry hands.
DATA TABLE

Part 2: Melting Point of the Pure BHT
Melting Point of BHT = _________°C

Part 3: Determine the $K_f$ of BHT with Cetyl Alcohol

<table>
<thead>
<tr>
<th>Mass BHT</th>
<th>g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Cetyl Alcohol</td>
<td>g</td>
</tr>
<tr>
<td>Melting Point BHT &amp; CA</td>
<td>°C</td>
</tr>
</tbody>
</table>

Part 4: Determine the Molar Mass of an Unknown Solid

<table>
<thead>
<tr>
<th>Mass BHT</th>
<th>g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Unknown</td>
<td>g</td>
</tr>
<tr>
<td>Melting Point BHT &amp; Unknown</td>
<td>°C</td>
</tr>
</tbody>
</table>

Calculations
Part 3: Determine the $K_f$ of BHT with Cetyl Alcohol
1. What is the freezing point depression ($\Delta T_f$) of the BHT and cetyl alcohol mixture?

2. What is the molality of the BHT and cetyl alcohol mixture?

3. What is the freezing point depression constant ($k_f$) of BHT?

Part 4: Determine the Molar Mass of an Unknown Solid
1. Using you equation from the pre-lab, determine the molar mass of you unknown.

2. Obtain the accepted value, and calculate your percent error for this lab.
Post Lab Analysis

1. List two possible sources of error for your lab, and explain how those errors affected your accuracy.

2. How would you have improved your execution of the lab?

3. Draw a series of molecular models showing how:
   a. BHT undergoes the physical change of melting when it is pure
   b. BHT undergoes the physical change of melting when mixed with cetyl alcohol