Molecular Mass by Freezing Point Depression

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1   Purpose

The purpose of this experiment is to determine the molecular mass of organic compounds which are dissolved in a solvent by noting the depression in the freezing point of the solution as compared to the freezing point of pure solvent since freezing point depends only on the number of particles that are dissolved.

2   Procedure

A measured mass of about 8 grams of Butylated hydroxytoluene (BHT) is placed into a test tube with a thermometer and stirring wire which is then put into a hot water bath. Once the water bath reaches 90°C, the test tube is removed and the temperature of the BHT is recorded every 20 seconds while being stirred continuously. The values are recorded until five constant measurements are taken.

The same procedure is then followed two more times except the BHT is mixed with either 1 gram of *para*-dichlorobenzene or 1 gram of the unknown compound.

3 Data

The following data were collected:

3.1 Pure BHT

Mass of BHT melted was 7.90g

Time (s)	T (°C)
20	85.9
40	83.2
60	81.8
80	78.6
100	75.8
120	73.9
140	72.0
160	70.9
180	69.0
200	68.8
220	68.8
240	68.8
260	68.8
280	68.7
300	68.7

3.2 BHT and *para*-dichlorobenzene 3.3 BHT and the unknown

Mass of BHT melted was 7.90g

Mass of *para*-dichlorobenzene melted was 1.05g

Mass of BHT melted was 8.46g

Mass of unknown melted was 1.156g

Time (s)	T (°C)
20	87.0
40	85.1
60	82.9
80	81.3
100	78.6
120	76.1
140	73.9
160	71.9
180	70.2
200	67.9
220	66.2
240	64.0
260	62.0
280	61.0
300	59.6
320	58.3
340	58.3
360	58.5
380	58.5
400	58.0
420	57.8
440	57.5
460	57.3

Time (s)	T (°C)
20	84.0
40	82.5
60	80.9
80	78.1
100	76.7
120	75.0
140	73.2
160	71.6
180	69.5
200	67.3
220	65.9
240	64.1
260	62.9
280	61.9
300	61.8
320	61.7
340	61.5
360	61.1
380	61.0
400	60.5
420	60.0
440	59.5
460	59.1

4 Calculations

For each pure substance or solution, the freezing point is the temperature value at the point of intersection of the two calculated least-squares linear curves, each which model a certain part of the data. The curves relate time and temperature which are t and T, respectively.

For BHT, the two curves are $T = -0.112t + 87.81$ and $T = 68.8$. Since the only possible intersection is when $T = 68.8°$C, the freezing point for BHT is $68.8°$C.

For BHT and *para*-dichlorobenzene, the curves are $T = -0.105t + 89.14$ and $T = -0.0145t + 63.91$. Using a simultaneous equation solver, the intersection is when $T = 59.9°$C, so the freezing point of the solution is at $59.5°$C.

For BHT and the unknown, the curves are $T = -0.0918t + 86.0$ and $T = -0.0240t + 70.1$. Again, using a simultaneous equation solver, the the intersection, and hence the freezing point, is at $64.5°$C.

The change in freezing point when BHT is a solvent is

$$\Delta T_{fp} = T_{fp_{\text{BHT}}} - T_{fp_{\text{solute}}} \tag{1}$$

Thus, for the solution of BHT and *para*-dichlorobenzene, $\Delta T_{fp} = 68.8°\text{C} - 59.9°\text{C} = 8.9°\text{C}$. For BHT and the unknown, $\Delta T_{fp} = 68.8°\text{C} - 64.5°\text{C} = 4.3°\text{C}$.

The relation between the amount of solute and the change in freezing point is

$$\Delta T_{fp} = k_{fp}m \tag{2}$$

Where k_{fp} is the freezing point depression constant for the solvent and m is the molality of the solution.

There were 7.90g of BHT and 1.05g of *para*-dichlorobenzene. The molar mass of *para*-dichlorobenzene is $146.992\frac{\text{g}}{\text{mol}}$. Then there are $1.05\text{g} \cdot \frac{1}{146.992\frac{\text{g}}{\text{mol}}} = 0.00714\text{mol}$ of solute. The solvent's mass is $7.90\text{g} \cdot \frac{1\text{kg}}{1000\text{g}} = 0.00790\text{kg}$. Then, the molality of the solution is $\frac{0.00714\text{mol}}{0.00790\text{kg}} = 0.904\text{m}$. Now, substituting values into equation 2,

$$\begin{aligned}
8.9°\text{C} &= k_{fp} \cdot 0.904\text{m} \\
k_{fp} &= 9.85\frac{°\text{C}}{\text{m}}
\end{aligned}$$

From this, we can calculate the molar mass of the unknown substance. Using equation 2, the freezing point depression constant, and the depression for the unknown,

$$\begin{aligned}
4.3°\text{C} &= 9.85\frac{°\text{C}}{\text{m}} \cdot m \\
m &= 0.437\text{m}
\end{aligned}$$

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Multiplying the molality by the mass of the solvent, $8.46\text{g} \cdot \frac{1\text{kg}}{1000\text{g}} = 0.00846\text{kg}$, will give the number of moles of the unknown solute which is $0.437\text{m} \cdot 0.00846\text{kg} = 0.00370\text{mol}$ and then dividing the mass of the unknown used by this will give the molar mass of the unknown, $\frac{1.156\text{g}}{0.00370\text{mol}} = 312 \cdot \frac{\text{g}}{\text{mol}}$

5   Discussion

1. Colligative properties are factors that determine how the properties of a solution will change depending on the concentration of the solute, irrespective of the identity of the solute. Examples are freezing point depression, boiling point elevation, vapor pressure, and osmotic pressure.

2. Fig. 1 is a standard phase diagram of a pure substance whereas Fig. 2 is the same substance but with the addition of a solute. Due to the freezing point depression, the line between solid and liquid phases is shifted to the left so that the melting point is at a lower temperature. Also, the due to boiling point elevation, the line to the gas phase is lowered so the boiling point is higher.

3. The least precise measurement is the recording of the temperature every 20 seconds. First of all, the thermometers in use can only read to one decimal place, and since they are being read in the region from 50-80, there are effectively 3 significant digits.

4. It is advantageous to choose a solvent with a large value for k_{fp} because larger drops in the freezing point can be observed with less solute per unit of solvent in comparison to a small k_{fp} value. This is because with the same concentrations, the solution with the larger k_{fp} value will have a larger drop in accordance to equation 2. Basically, it is easier to record a more visible drop in freezing point than a small drop and a large k_{fp} value since the drop is directly proportional to the value.

5. Pure solvent shows a level horizontal curve as solidification occurs since at that point, the kinetic energy is not being lowered, but instead the potential energy of the solvent is lowering. A result of this is that the observed temperature remains constant as the liquid is assembling itself into a solid. When a solute is added to the solvent, when one of the compounds is still losing kinetic energy, the other may already instead be losing potential energy. This means that the solution is solidifying (reducing potential energy) and cooling down (reducing kinetic energy) at the same time. This will be reflected as a curve with a slightly downward slope as the temperature is still lowering over time.