Determination of the Molecular Weight of an Unknown Compound Using Freezing-Point Depression of Tert-Butyl Alcohol (12-point font, Bold-Type, Centered)

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Objective

We determined the molecular weight of an unknown compound by determining the freezing-point depression of a solution of this unknown compound and tert-butyl alcohol. (12-point font, single-spaced)

Introduction

Colligative properties are properties that depend upon the number of particles that are in a solution and not the type of particle.[1] For example, adding a solute, such as sugar, to water will cause the freezing point of the solution to be lower than that of water. In addition, the vapor pressure of the water will decrease, and the boiling point of the solution will increase. Colligative properties have many practical purposes such as adding particles (e.g. salt or sand) to icy sidewalks to lower their freezing points making the sidewalks less dangerous.[1]

We used the colligative property of freezing-point depression to determine the molecular weight of an unknown compound. This technique can be coupled with other quantitative and qualitative techniques in the identification of compounds.[2]

Experimental

To determine the molecular weight of an unknown compound, we followed the procedure outlined in "Experiment 1: Colligative Properties…" [3] A summary from reference 3 is included here: (There were no deviations from the outlined procedure.) Twenty grams of the solvent, tert-butyl alcohol, was first heated to completely melt it. The solvent was allowed to cool in an ice-bath while temperature measurements were taken every 30 seconds for twelve minutes. The solvent was reheated to melt it, and 0.50 g of the unknown compound was added. After the solute was completely dissolved, the solution was cooled in the ice bath taking temperature measurements every 30 seconds for twelve minutes. The solution was reheated to melt it, and an additional

0.50 g of the unknown compound was added, and the cooling procedure repeated. The molecular weights were determined according to the Equation 1.

Calculations and Theory

We added a known quantity of our unknown compound to a known quantity of tert-butyl alcohol collecting temperature data with respect to time as the solution froze.[3] We determined the freezing-point of the pure solvent and the two trials of the solution through plotting a graph of T (°C) vs. time (min.) and determining best-fit lines through the two portions of the data as in Figure 1.

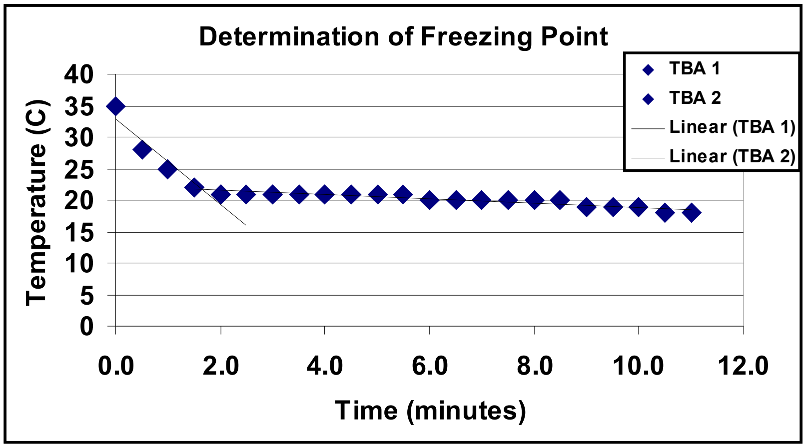

Figure 1. Determination of the freezing point from a plot of temperature versus time for the cooling cycle of a pure solvent (10-point font.)

Because colligative properties depend upon how much of the solute is added, the number of moles of the solute can be calculated, and thus, the molar mass of the solute can be determined. The derivation of equations for determining the molar mass of the solute are as follows: The formula for freezing-point depression[1] is

$$\Delta T_f = K_f m \qquad (1)$$

T_f^0 is the freezing point of the pure solvent (tert-butyl alcohol in this experiment), T_f is the freezing point of the solution, ΔT_f is the change in the freezing point depression, K_f is the freezing-point constant, and m is the molality of the solution. The formula can be rearranged to solve for the molality:

$$m = \frac{\Delta T_f}{K_f} \tag{2}$$

The molality is equal to quotient of the moles of the solute and the kilograms of the solvent as shown in Equation 3. In addition, the moles of the solute can be determined by the quotient of the grams of the solute and the molecular weight (MM) of the solute as shown in Equation 3.

$$molality = m = \frac{mol\_solute}{kg\_solvent} = \frac{\frac{g\_solute}{MM\_solute}}{kg\_solvent} \tag{3}$$

Equation 3 can be rearranged to yield an expression for the molecular weight of the solute, or unknown compound.

$$molality = m = \frac{mol\_solute}{kg\_solvent} = \frac{\frac{g\_solute}{MM\_solute}}{kg\_solvent} \tag{4}$$

Include a brief introduction to the experiment including the theory of the experimental procedures. Include balanced chemical equations for the reactions. (12-point font, 1.5 spacing)

Results

Table 1. Times and temperatures for cooling cycles of pure solvent, solution 1, and solution 2 (10-point font.)

Time (minutes)	TBA temp °C	Sol'n 1 temp °C	Sol'n 2 temp °C
0.0	35	35	33
0.5	28	26	25
1.0	25	22	20
1.5	22	20	18.5
2.0	21	19	16
2.5	21	19	16
3.0	21	19	13
3.5	21	19	13
4.0	21	19	13
4.5	21	19	16
5.0	21	19	16.5
5.5	21	19	16.5
6.0	20	18.5	16.5
6.5	20	18.5	16.5
7.0	20	18	16
7.5	20	18	16
8.0	20	18	16
8.5	20	17.5	16
9.0	19	17.5	15.5
9.5	19	17	15.5
10.0	19	17	15.5
10.5	18	16.5	15.5
11.0	18	16.5	15.5

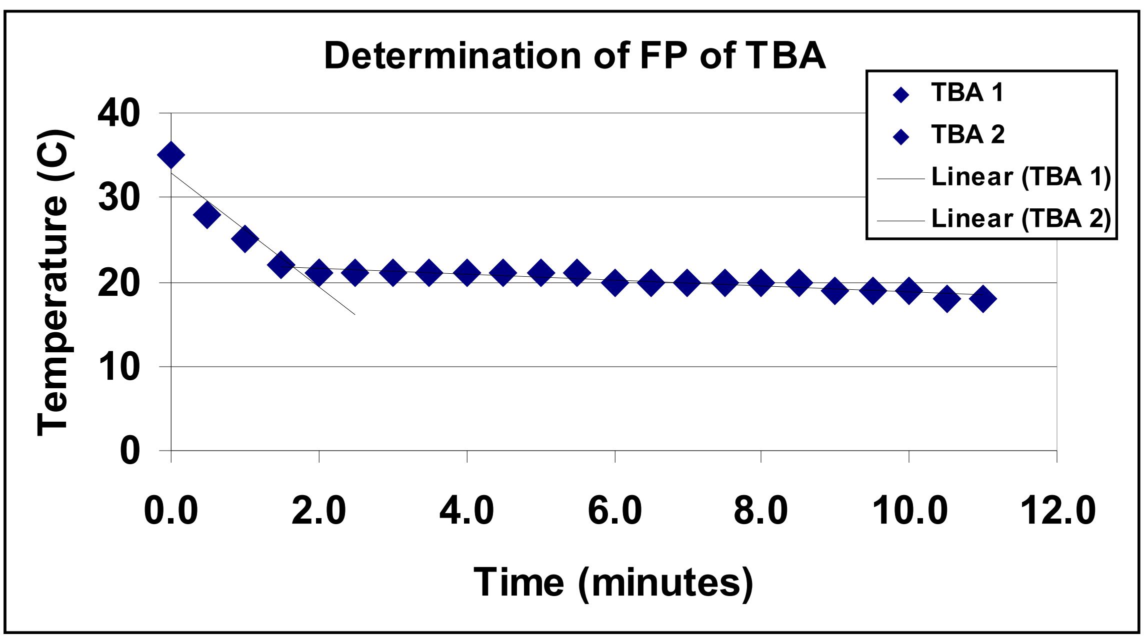

Figure 2. Temperature versus time for the cooling cycle of pure solvent (tert-butyl alcohol) (10-point font.)

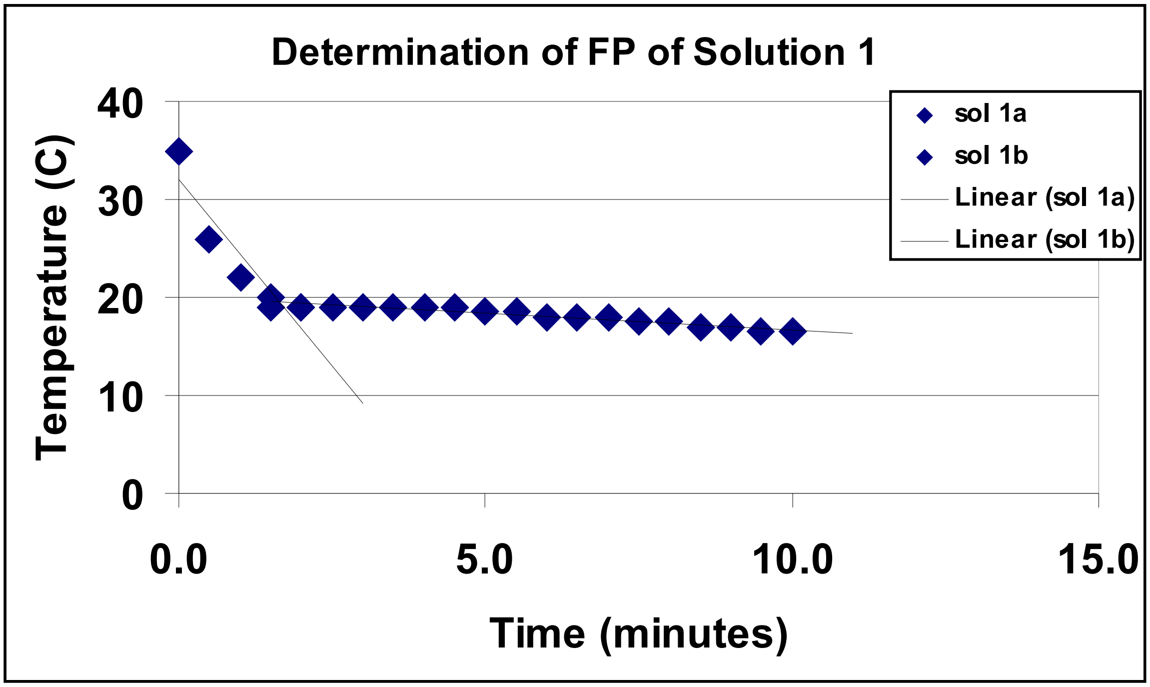

Figure 3. Temperature versus time for the cooling cycle of solution 1 (tert-butyl alcohol and 0.50 g of unknown solute) (10-point font.)

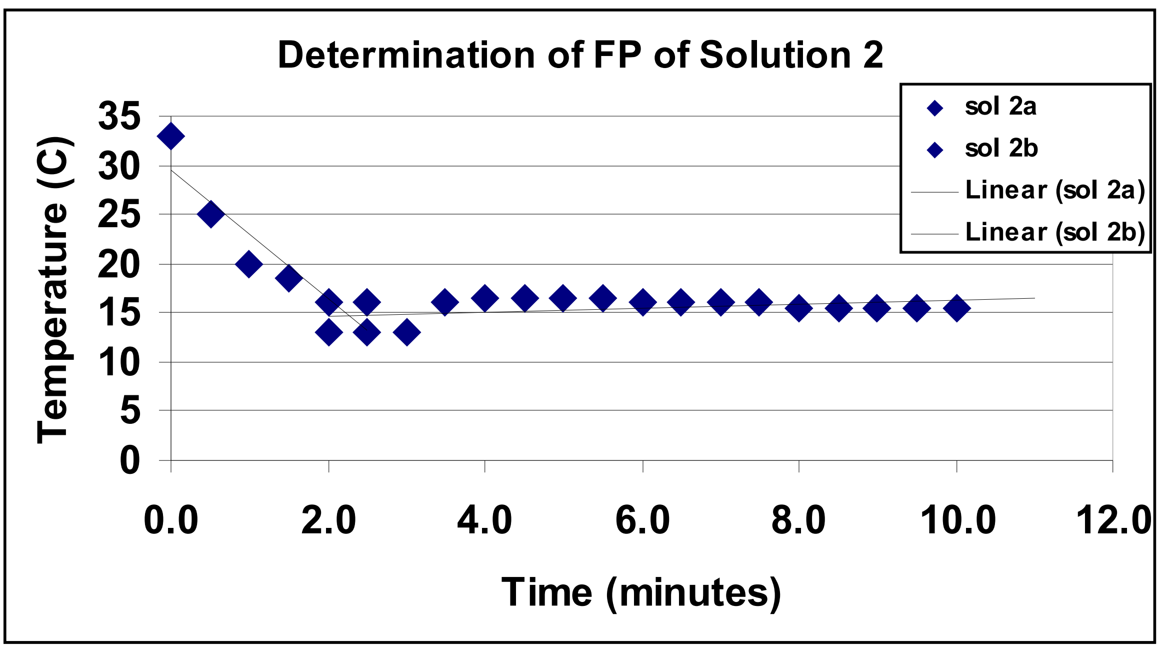

Figure 4. Temperature versus time for the cooling cycle of solution 2 (tert-butyl alcohol and 1.00 g of unknown solute) (10-point font.)

Table 2. Freezing points for the pure solvent and two solutisions obtained from Figures 2 through 4 (10-point font.)

Freezing Point (from graphs)		
Pure TBA	Solution 1	Solution 2
21	18.9	16.2

Table 3. Molecular weights of the unknown solutes from solution 1 and solution 2 (10-point font.)

Molecular Weights of UNK Solute	
Solution 1	**Solution 2**
99.1 g/mol	86.9 g/mol

Discussion

The average molecular weight of the unknown solute was 93.0 g/mol as shown in Table 3, and the accepted value for the molecular weight of this compound was 122.8 g/mol. The percent error of our experiment was 24.3 %. Whether this percent error is a large or small error, depends on the purpose of determining the molecular weight. If this technique of freezing-point depression is to be used as a quantitative tool for determining the identify of unknown compounds, our percent error is large: An accurate identification of the compound cannot be made with an error this large.

Sources of error in this experiment could include both human and instrumental: We did not weigh out the 0.50 g of the unknown compound ourselves. Thus, we do not know if any of the compound was spilled to cause the reading to be in error. An additional source of instrumental error could be the thermometer and that the thermometer was not calibrated. Sources of human error could include misreading the meniscus on the graduated cylinder, misreading the temperature on the thermometer, and not having the most accurate best-fit line on the freezing-point graphs (Figures 2 through 4). The most accurate way to determine the best-fit line would be using a program similar to Microsoft Excel®.

Conclusions

We determined the molecular weight of an unknown compound using the technique of freezing-point depression. The molar mass determined was 93.0 g/mol yielding a percent error of 24.3 % from the actual value of 122.8 g/mol. This experiment was the first time that we performed this procedure and because we obtained only 24.3 % error, we feel that overall the experiment was a success. We did successfully accomplish our objective of determining the molar mass of this compound. For this technique to be used in the identification of unknown compounds, a percent error of less than 5 % must be obtained and must be used in conjunction with a data source of known compounds and their molecular weights.

References

1. Chang, R. *Chemistry*, 8th ed.; McGraw-Hill: New York, 2004.
2. Willard, H. H.; Merritt, L. L., Jr.; Dean, J. A.; Settle, F. A., Jr. *Instrumental Methods of Analysis*, 7th ed.; Wadsworth: Belmont, CA, 1988.
3. *Laboratory Manual for Chemistry 1221, Spring 2005*; Millsaps College Department of Chemistry: Jackson, MS, 2005.