Experiment
15

Using Freezing-Point Depression to Find Molecular Weight

When a solute is dissolved in a solvent, the freezing temperature is lowered in proportion to the number of moles of solute added. This property, known as freezing-point depression, is a *colligative property*; that is, it depends on the ratio of solute and solvent particles, not on the nature of the substance itself. The equation that shows this relationship is:

$$\Delta T = K_f \bullet m$$

where ΔT is the freezing point depression, K_f is the freezing point depression constant for a particular solvent (8.8°C-kg/mol for phenyl salicylate in this experiment), and m is the molality of the solution (in mol solute/kg solvent).

In this experiment, you will first find the freezing temperature of the pure solvent, phenyl salicylate, (PS). You will then add a known mass of an unknown solute to a known mass of PS, and determine the lowering of the freezing temperature of the solution.. By measuring the freezing point depression, ΔT, and the mass of the unknown added, you can use the formula above to find the molecular weight of the unknown solute, in g/mol.

OBJECTIVES

In this experiment, you will

- Determine the freezing temperature of pure phenyl salicylate.
- Determine the freezing temperature of a solution of an unknown solute and phenyl salicylate.
- Examine the freezing curves for each.
- Calculate the experimental molecular weight of the unknown solute.

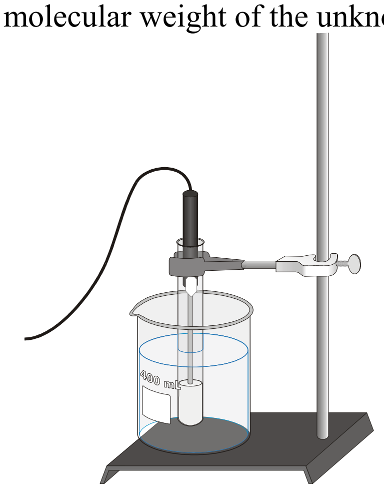


Figure 1

MATERIALS

computer
Vernier computer interface
Logger*Pro*
utility clamp
18 × 150 mm test tube
Phenyl salicylate

Temperature Probe
400 mL beaker
ring stand
unknown
thermometer

PROCEDURE

1. Obtain and wear goggles.

2. Connect the Temperature Probe to the computer interface. Prepare the computer for data collection by opening the file "15 Freezing Pt Depression" from the *Chemistry with Computers* folder.

Part I Freezing Temperature of Pure Lauric Acid

3. Add about 300 mL of tap water to a 400 mL beaker. Place the beaker on a hot plate on the the base of the ring stand. Heat the water until it reaches 50°-55°C. Use the thermometer to monitor this temperature. Do not let it get too hot.

4. Obtain a large test tube and fill it 2/3 full with phenyl salicylate.
   Obtain a second large test tube and place it in a small beaker and place on the balance. Zero the balance using the tare button. Fill the test tube about 2/3 full with phenyl salicylate and record the mass. Then add about 2.00 g of your unknown and record the mass.

5. Clamp the first test tube with the pure PS to a ring stand and immerse the test tube in the water as far as is convenient. When the PS is almost melted insert the Temperature Probe into the hot PS. About 30 seconds are required for the probe to warm up to the temperature of its surroundings and give correct temperature readings.

6. When the PS is all melted, carefully remove the test tube from the hot water and swing it away from the hot plate. Wipe the outside of the test tube dry with a paper towel. Make sure that all the PS is melted and that the temperature showing on the graph is not higher than 50°C. Then click Collect to begin data collection. If the temperature is higher than 50°C, allow it to cool below 50°C and then click Collect to begin data collection.

7. With a very slight up and down motion of the Temperature Probe, *continuously* stir the PS during the cooling. Hold the top of the probe and *not* its wire.

8. Continue with the experiment until data collection has stopped after 10 minutes. Use the hot water bath to melt the probe out of the solid PS. *Do not* attempt to pull the probe out—this might damage it. Carefully wipe any excess PS liquid and solid from the probe with a paper towel or tissue.

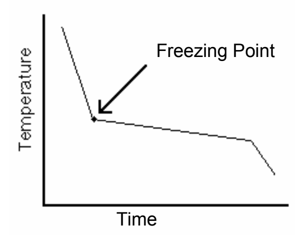
9. To determine the freezing temperature of pure phenyl salicylate, you need to determine the mean (or average) temperature in the portion of graph with nearly constant temperature. Move the mouse pointer to the beginning of the graph's flat part. Press the mouse button and hold it down as you drag across the flat part of the curve, selecting only the points in the plateau. Click on the Statistics button, STAT. The mean temperature value for the selected data is listed in the statistics box on the graph. Record this value as the freezing temperature of phenyl salicylate. Close the statistics box.

Part II Freezing Temperature of a Solution of the Unknown and Phenyl Salicylate

10. Store your data by choosing Store Latest Run from the Experiment menu. Hide the curve from your first run by clicking on the vertical axis label and unchecking the appropriate box. Click OK.

11. Use the second test tube containing the mixture of your unknown and PS. Repeat Steps 5-8 to determine the freezing point of this mixture.

12. When you have completed Step 8, click on the Examine button, . To determine the freezing point of this solution, you need to determine the temperature at which the mixture initially started to freeze. Unlike pure PS, cooling a mixture results in a gradual linear decrease in temperature during the time period when freezing takes place. As you move the mouse cursor across the graph, the temperature (y) and time (x) data points are displayed in the examine box on the graph. Locate the initial freezing temperature of the solution, as shown here. Record the freezing point in your data table.



13. To print a graph of temperature *vs*. time showing both data runs:
    a. Click on the vertical-axis label of the graph. To display both temperature runs, click More, and check the Run 1 and Latest Temperature boxes. Click OK.
    b. Label both curves by choosing Text Annotation from the Insert menu, and typing "Phenyl Salicylate" (or "Unknown-Phenyl salicylate mixture") in the edit box. Then drag each box to a position on or near its respective curve.
    c. Print the graph.

14. If time permits, weigh an additional 2.00 grams of your unknown and add this to the unknown-PS mixture. Repeat steps 11-13 (including repeating steps 5-8)

PROCESSING THE DATA

1. Determine the difference in freezing temperatures, Δt, between the pure PS (t_1) and the mixture of your unknown and PS (t_2). Use the formula, $\Delta t = t_1 - t_2$.
2. Calculate molality (m), in mol/kg, using the formula, $\Delta t = K_f \cdot m$ (K_f = 8.8°C-kg/mol for Phenyl salicylate).
3. Calculate moles of your unknown solute, using the answer in Step 2 (in mol/kg) and the mass (in kg) of PS solvent.
4. Calculate the *experimental* molecular weight of your unknown, in g/mol. Use the original mass of unknown from your data table, and the moles of your unknown you found in the previous step.
5. If you did a second sample of the mixture (Step 14 above), repeat these calculations, remembering to use the total mass of unknown in the second mixture. Average the two values you obtained for the molecular weight.

EXTENSION

Here is another method that can be used to determine the freezing temperature from your data in Part II. With a graph of the Part II data displayed, use this procedure:

1. Move the mouse pointer to the initial part of the cooling curve, where the temperature has an initial rapid decrease (before freezing occurred). Press the mouse button and hold it down as you drag across the linear region of this steep temperature decrease.
2. Click on the Linear Fit button, .

3. Now press the mouse button and drag over the next linear region of the curve (the gently sloping section of the curve where freezing took place). Press the mouse button and hold it down as you drag only this linear region of the curve.
4. Click again. The graph should now have two regression lines displayed.
5. Choose Interpolate from the Analyze menu. Move the mouse pointer left to the point where the two regression lines intersect. When the small circles on each cursor line overlap each other at the intersection, the temperatures shown in either examine box should be equal to the freezing temperature for the benzoic acid-lauric acid mixture.

DATA AND CALCULATIONS TRIAL #1

Mass of phenyl salicylate (PS)	g
Mass of unknown (**Unknown # _________**)	g
Freezing temperature of pure PS	°C
Freezing point of the mixture	°C

Freezing temperature depression, Δt	°C
Molality, *m*	mol/kg
Moles of unknown	mol
Molecular weight of unknown	g/mol

DATA AND CALCULATIONS TRIAL #2

Mass of phenyl salicylate (PS)	g
Total mass of unknown (**Unknown # __________**)	g
Freezing temperature of pure PS	°C
Freezing point of the mixture	°C

Freezing temperature depression, Δt	°C
Molality, *m*	mol/kg
Moles of unknown	mol
Molecular weight of unknown	g/mol

Average MW of Unknown ________________________

Lab #13

PRESTUDY

NAME ______________________________________ SECTION _____________

Determination of Molecular Weight by Freezing Point Depression

1. A student determines the freezing point of a solution of 0.867 g of an unknown sample in 28.25 g of benzene. The student obtains the following time-temperature data:

Time (min)	0	0.5	1	1.5	2	2.5
Temperature (°C)	10.50	10.00	9.45	8.85	8.30	7.75
Time (min)	3	3.5	4	4.5	5	5.5
Temperature (°C)	7.19	6.56	6.10	5.50	5.20	5.00
Time (min)	6	6.5	7	7.5	8	8.5
Temperature (°C)	4.95	4.96	4.95	4.90	4.90	4.81

(a) Plot temperature vs. time on a graph. From the graph, estimate the freezing point of the solution to the nearest 0.01 °C, by determining the intersection of the two straight line portions of this cooling curve.(5 points)

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(b) Assuming k_f for benzene is 5.12 °C/ m and its freezing point is 5.48 °C, calculate the gram molecular weight of the unknown.(5 points)