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 (3.9°C-kg/mol for lauric acid in this experiment[1]), 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, lauric acid, $CH_3(CH_2)_{10}COOH$. You will then add a known mass of benzoic acid solute, C_6H_5COOH, to a known mass of lauric acid, and determine the lowering of the freezing temperature of the solution. In an earlier experiment, you observed the effect on the cooling behavior at the freezing point when a solute was added to a pure substance. By measuring the freezing point depression, Δt, and the mass of benzoic acid, you can use the formula above to find the molecular weight of the benzoic acid solute, in g/mole.

OBJECTIVES

- Determine the freezing temperature of pure lauric acid.
- Determine the freezing temperature of a solution of benzoic acid and lauric acid.
- Examine the freezing curves of pure lauric acid and the solution of benzoic acid and lauric acid.
- Calculate the experimental molecular weight of benzoic acid.
- Compare it to the accepted molecular weight for benzoic acid.

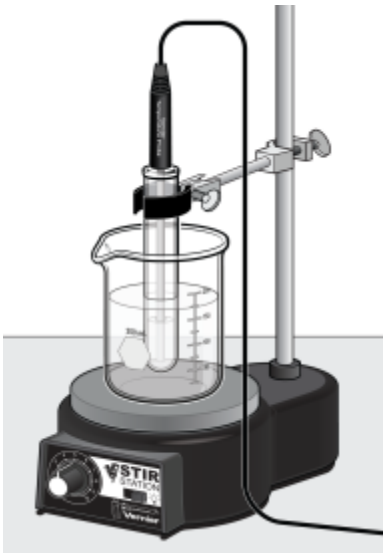

Figure 1

[1] "The Computer-Based Laboratory," Journal of Chemical Education: Software, 1988, Vol. 1A, No. 2, p. 73.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis app
Vernier data-collection interface
Temperature Probe
Stir Station and magnetic stir bar
utility clamp
400 mL beaker
18 × 150 mL test tube
lauric acid
benzoic acid
thermometer
water

PROCEDURE

1. Obtain and wear goggles.

2. Connect the Temperature Probe to the data-collection interface, and then connect the interface to your Chromebook or mobile device. Launch Graphical Analysis.

3. Click or tap Mode to open Data Collection Settings. Change Rate to 0.5 samples/s and End Collection to 600 s. Click or tap Done.

Part I Freezing Temperature of Pure Lauric Acid

4. Add about 300 mL of tap water with a temperature between 20 and 25°C to a 400 mL beaker. Place the beaker on the base of the Stir Station. Add a magnetic stir bar to the beaker and stir the water gently to maintain a uniform temperature.

5. Use a utility clamp to obtain a test tube containing hot melted lauric acid from your teacher. Fasten the utility clamp at the top of the test tube. **WARNING**: *Solid lauric acid,* $CH_3(CH_2)_{10}COOH$: *Causes eye irritation and mild skin irritation*. *Do not to spill the hot lauric acid on yourself. Do not touch the bottom of the test tube*.

6. Insert the Temperature Probe into the hot lauric acid. About 30 seconds are required for the probe to warm up to the temperature of its surroundings and give correct temperature readings. During this time, fasten the utility clamp to the Stir Station so the test tube is above the water bath.

7. After the 30 seconds have elapsed, click or tap Collect to start data collection.

8. Lower the test tube into the water bath. Make sure the water level outside the test tube is higher than the lauric acid level inside the test tube. If the lauric acid is not above 50°C, obtain another lauric acid sample and begin again.

9. With a very slight up and down motion of the Temperature Probe, *continuously* stir the lauric acid during the cooling. Hold the top of the probe and *not* its wire. Stop moving the probe when it sticks in the solidifying lauric acid.

10. Data collection will stop after 10 minutes. Use the hot water bath provided by your teacher to melt the probe out of the solid lauric acid. Do *not* attempt to pull the probe out—this might damage it. Carefully wipe any excess lauric acid liquid from the probe with a paper towel or tissue. Return the test tube containing lauric acid to the place directed by your teacher.

11. To determine the freezing temperature of pure lauric acid, you need to analyze the portion of the graph with nearly constant temperature.

    a. Select the flat portion of the graph.

    b. Click or tap Graph Tools, , and choose View Statistics.

    c. Record the mean (average) temperature that represents the freezing temperature of pure lauric acid.

Part II Freezing Temperature of a Solution of Benzoic Acid and Lauric Acid

12. Obtain a test tube containing a melted solution with ~1 g of benzoic acid dissolved in ~8 g of lauric acid. Record the *precise masses* of benzoic acid and lauric acid as indicated on the label of the test tube. Repeat Steps 4–10. **Note**: The previous data set is automatically saved. **DANGER**: *Solid benzoic acid,* C_6H_5COOH: *Do not eat or drink when using this product—harmful if swallowed. Causes serious eye irritation. May cause respiratory irritation*.

13. To determine the freezing point of the benzoic acid-lauric acid solution, you need to determine the temperature at which the mixture first started to freeze. Unlike pure lauric acid, cooling a mixture of benzoic acid and lauric acid results in a slow gradual drop in temperature during the time period when freezing takes place. Examine the data points to locate the freezing point of the solution (see Figure 2 for an example). Record the freezing point in the Data and Calculations table.

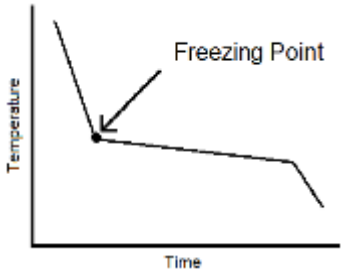

Figure 2

14. A good way to compare the freezing curves of the pure substance and the mixture is to view both sets of data on one graph. Click or tap the y-axis and select the data you want to view. Dismiss the dialogue to view the graph. Both temperature runs are now be displayed on the same graph.

15. (Optional) Annotate the curves as *pure lauric acid* or *benzoic acid and lauric acid*. Export, download, or print a graph of temperature *vs*. time (with two curves displayed).

PROCESSING THE DATA

1. Determine the difference in freezing temperatures, Δt, between the pure lauric acid (t_1) and the mixture of lauric acid and benzoic acid (t_2). Use the formula, $\Delta t = t_1 - t_2$.

2. Calculate molality (m), in mol/kg, using the formula, $\Delta t = K_f \bullet m$ (K_f = 3.9°C-kg/mol for lauric acid).

3. Calculate moles of benzoic acid solute, using the answer in Step 2 (in mol/kg) and the mass (in kg) of lauric acid solvent.

4. Calculate the *experimental* molecular weight of benzoic acid, in g/mol. Use the original mass of benzoic acid from the Data and Calculations table, and the moles of benzoic acid you found in the previous step.

5. Determine the *accepted* molecular weight for benzoic acid from its formula, C_6H_5COOH.

6. Calculate the percent error.

DATA AND CALCULATIONS

Mass of lauric acid	g
Mass of benzoic acid	g
Freezing temperature of pure lauric acid	°C
Freezing point of the benzoic acid–lauric acid mixture	°C

Freezing temperature depression, Δt	°C
Molality, *m*	mol/kg
Moles of benzoic acid	mol
Molecular weight of benzoic acid (experimental)	g/mol
Molecular weight of benzoic acid (accepted)	g/mol
Percent error	%

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. Select a linear region in the initial part of the cooling curve where the temperature has an initial rapid decrease (before freezing occurred).
2. Click or tap Graph Tools, , and choose Apply Curve Fit. Select Linear as the curve fit and Dismiss the Curve Fit box.
3. Select the next linear region of the curve (the gently sloping section where freezing took place).
4. Click or tap Graph Tools, , and choose Apply Curve Fit. Select Linear as the curve fit and Dismiss the Curve Fit box. The graph should now have two regression lines displayed.
5. Click or tap Graph Tools, , and turn on Interpolate. Dismiss the Graph Tools box and click or tap the graph to interpolate. Click or tap the point where the two regression lines intersect. When the small circles on each line overlap each other at the intersection, the temperatures shown in either interpolate box should be equal to the freezing temperature for the benzoic acid-lauric acid mixture.