

Determination of Molar Mass by Freezing-Point Depression

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

$$\Delta T_f = K_f \times m \times i$$

where ΔT_f is the freezing point depression, K_f is the freezing point depression constant for a particular solvent ($3.9^\circ\text{C}\cdot\text{kg}/\text{mol}$ for lauric acid in this experiment¹), i is the van't Hoff factor, and m is the molality of the solution (in mol solute/kg solvent). Since lauric acid is *not* ionic, its van't Hoff factor is essentially equal to 1.

OBJECTIVES

In this experiment, you will

- Determine the freezing temperature of the pure solvent, lauric acid.
- Determine the freezing temperature of a mixture of lauric acid and benzoic acid.
- Calculate the freezing point depression of the mixture.
- Calculate the molecular weight of benzoic acid.

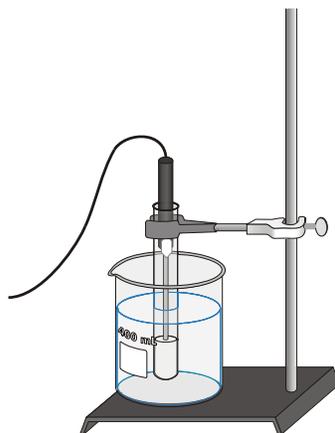


Figure 1

MATERIALS

Data Collection Mechanism
Temperature Probe
ring stand
400 mL beaker
Tissue or paper towels

lauric acid, $\text{CH}_3(\text{CH}_2)_{10}\text{COOH}$
lauric acid-benzoic acid mixture
hot water bath
utility clamp
two 18×150 mm test tubes (if pre-made samples are not provided by your teacher)

¹“The Computer-Based Laboratory”, *Journal of Chemical Education: Software*, 1988, Vol.1A, No. 2, p. 73.

PROCEDURE

1. Obtain and wear goggles.
2. Set up the data collection system.
 - a. Connect a Temperature Probe to the interface.
 - b. Start the data collection program.
 - c. Set up the time graph for 10 seconds per sample and 60 samples.

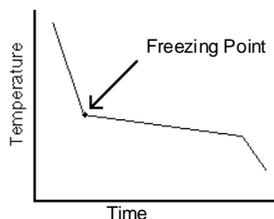
Part I: Determine the Freezing Temperature of Pure Lauric Acid

3. Add about 300 mL of tap water with a temperature of 20-25°C to a 400 mL beaker. Place the beaker on the base of the ring stand.
4. Use a utility clamp to obtain a test tube containing hot, melted lauric acid from your instructor. Fasten the utility clamp at the top of the test tube. **CAUTION:** *Be careful not to spill the hot lauric acid on yourself and do not touch the bottom of the test tube.*
5. Insert the Temperature Probe into the hot lauric acid. Fasten the utility clamp to the ring stand so the test tube is above the water bath.
6. Begin data collection. Lower the test tube into the water bath. Make sure the water level outside the test tube is higher than the lauric acid level in the test tube, as shown in Figure 1.
7. With a very slight up-and-down motion of the Temperature Probe, *continuously* stir the lauric acid for the ten-minute duration of the experiment. Do not allow the temperature probe to touch the bottom of the test tube.
8. When data collection is complete, use a hot water bath to melt the lauric acid enough to safely remove the Temperature Probe. Carefully wipe any excess lauric acid liquid from the probe with a paper towel or tissue.
9. The freezing temperature can be determined by finding the mean temperature in the portion of the graph with nearly constant temperature.
 - a. Select the data in the flat region of the graph.
 - b. Find the mean temperature for the selected data. Record this value.
 - c. Store the data, so that they can be used later.

The Determination of Molar Mass by Freezing-Point Depression

Part II: Determine the Freezing Point of a Solution of Benzoic Acid and Lauric Acid

10. 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 3-8.

11. The freezing point of the benzoic acid-lauric acid solution can be determined by finding the temperature at which the mixture initially started to freeze. Unlike pure lauric acid, the mixture results in a gradual linear decrease in temperature during freezing.
12. Print a graph showing both trials. (See the graph pictured in question 6 of the Pre-Lab Questions.)

DATA TABLE

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)	

PRE-LAB QUESTIONS

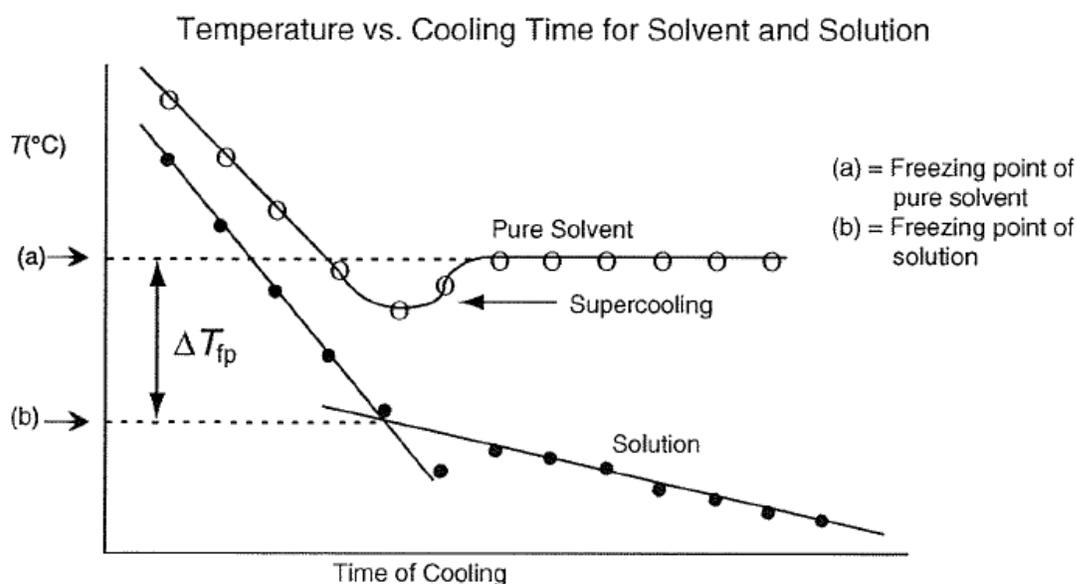
1. What types of intermolecular forces are present in a molecular solid such as lauric acid? Describe what is happening with regard to intermolecular forces as a molecular liquid freezes.
2. If you were able to choose a solvent for this experiment from the list below, which would you choose? Justify your answer.
 - Acetic Acid CH_3COOH $K_f = 3.90 \text{ }^\circ\text{C}\cdot\text{kg/mol}$
 - Benzene C_6H_6 $K_f = 5.12 \text{ }^\circ\text{C}\cdot\text{kg/mol}$
 - tert-Butanol $\text{C}_4\text{H}_9\text{OH}$ $K_f = 9.10 \text{ }^\circ\text{C}\cdot\text{kg/mol}$
 - Cyclohexane C_6H_{12} $K_f = 20.00 \text{ }^\circ\text{C}\cdot\text{kg/mol}$

The Determination of Molar Mass by Freezing-Point Depression

3. What is the equation for calculating molality? Why do we use molality rather than molarity as our concentration unit for this experiment?
4. Use the equation above along with the freezing-point depression equation to derive an expression for calculating the molar mass of a solute.
5. The following data were obtained in an experiment designed to determine the molar mass of a solute by freezing-point depression. The K_f of *para*-dichlorobenzene is $7.1\text{ }^\circ\text{C}\cdot\text{kg}/\text{mol}$

Mass of <i>para</i> -dichlorobenzene (g)	24.80 g
Mass of unknown solute (g)	2.04 g
Freezing temperature of pure <i>para</i> -dichlorobenzene ($^\circ\text{C}$)	53.02 $^\circ\text{C}$
Freezing point of the solution ($^\circ\text{C}$)	50.78 $^\circ\text{C}$

- (a) Calculate the freezing-point depression, ΔT_f of the solution.
 - (b) Calculate the molar mass of the unknown substance.
6. Examine the graph below. What laboratory technique best prevents supercooling?



POST-LAB QUESTIONS AND DATA ANALYSIS

1. Calculate molality (m), in mol/kg, using the formula $\Delta T_f = K_f \times m \times i$. The K_f value for lauric acid is $3.9^\circ\text{C}\cdot\text{kg/mol}$ and since lauric acid is a molecular solid, i is approximately equal to 1.
2. Calculate moles of benzoic acid solute, using the molality and the mass (in kg) of lauric acid solvent.
3. Calculate the *experimental* molecular weight of benzoic acid, in g/mol.
4. Determine the *accepted* molecular weight of benzoic acid from its formula, $\text{C}_6\text{H}_5\text{COOH}$.
5. Calculate the percent error between the experimental and accepted values.
6. Explain why the pure solvent shows a level horizontal curve as solidification occurs, but the curve for the solution slopes downward slightly.
7. A student spills some of the solvent before the solute was added. What effect does this error have on the calculated molar mass of the solute? Mathematically justify your answer.
8. A different student spills some of the solution before the freezing-point was determined. What effect does this error have on the calculated molar mass of the solution? Justify your answer.