

Reading assignment: Chang, Chemistry 9th edition, pp. 521-525.

Goals

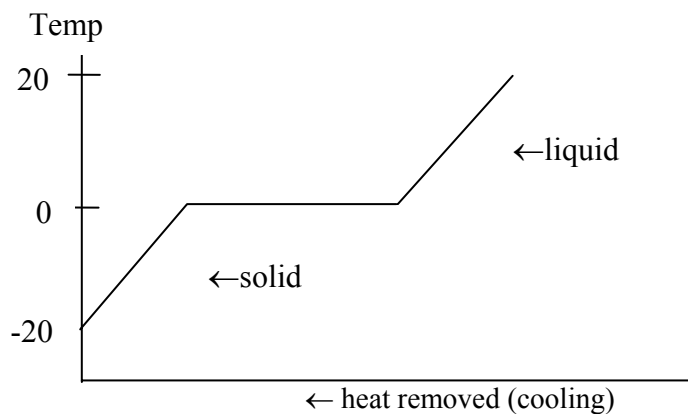
We will measure the freezing point depression of lauric acid that takes place with the addition of benzoic acid. From the freezing point depression of lauric acid we can determine the molar mass of benzoic acid.

Equipment and Supplies

LabPro interface, LoggerPro software, two stainless steel temperature probes, hot plate, test tube containing ~8 g lauric acid, test tube containing ~8 g lauric acid and ~1 g benzoic acid, 600 mL beaker, two 250 mL beakers, glass stirring rod. Bring a 3-½ inch diskette.

Discussion

When a liquid is cooled below the temperature at which it freezes (T_F) it will undergo a transition from the liquid state to the solid state. Ideally, when a pure substance freezes its temperature remains constant during the process. For example, pure water freezes at 0°C. Consider a sample of ice, initially at -20°C, being heated to 20°C. Once the ice reaches 0°C, the temperature will remain constant until the ice is completely melted. Once the ice is completely melted the temperature will then begin to increase to 20°C.



Freezing-Point Depression

When a nonvolatile solute is added to a liquid solvent, the freezing point of the solvent is lowered by an amount that is proportional to the molal concentration of the solute. This lowering (depression) of the freezing point of the solvent can be represented using the following equation:

$$\Delta T = K_F \cdot m$$

where K_F is called the freezing point depression constant and is a property of the solvent. The freezing point depression is also proportional to the molal concentration of the solute, m . Melting points and values of K_F are shown below for several common materials.

Material	mp (°C)	K_F $\left(\frac{\text{kg}^\circ\text{C}}{\text{mol}}\right)$	Material	mp (°C)	K_F $\left(\frac{\text{kg}^\circ\text{C}}{\text{mol}}\right)$
acetone	-94.9	4.04	lauric acid	45	3.9
acetic acid	16.7	3.90	naphthalene	80.5	6.94
ammonia	-77.7	0.957	phenol	40.5	7.40
aniline	-6.3	5.87	sulfuric acid	10	1.86
benzene	5.5	5.12	water	0.0	1.86
cyclohexane	6.6	20.0	o-xylene	-25	4.3

Freezing-point depression depends on the concentration of the solute. The molality of the solution is a measure of concentration and is defined as:

$$\text{molality} = \frac{\text{moles of solute}}{\text{kilograms of solvent}}$$

Unlike molarity, molality does not depend on temperature because the mass of the solvent doesn't change with temperature. Freezing-point depression is an example of a colligative property. Colligative properties are ones which depend on the relative amounts of solvents and solutes. Other examples of colligative properties include boiling-point elevation and osmotic pressure.

Sample Calculation 1

An 11.555 g sample of sodium chloride is dissolved in 100.000 g of water. What is the total mass of the solution? What is the molality of the solution?

$$\text{total mass} = 11.555 \text{ g} + 100.000 \text{ g} = 111.555 \text{ g.}$$

Calculation of the molality of the solution requires the number of moles of solute and the mass of the solvent in kilograms. The molar mass of NaCl is 58.44 g and allows a determination of the number of moles of solute:

$$\text{molality} = \frac{\text{moles of solute}}{\text{kilograms of solvent}} = \frac{(11.555 \text{ g NaCl}) \left(\frac{1 \text{ mol NaCl}}{58.44 \text{ g NaCl}} \right)}{(100.00 \text{ g H}_2\text{O}) \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)} = 1.977 \frac{\text{mol}}{\text{kg}} \text{ or } 1.977 \text{ m}$$

The next example shows how the number of moles of a solute can be found by measuring the freezing-point depression for the mixture.

Sample Calculation 2

Pure benzene freezes at 5.5°C. A solute is added to 500.00 g of benzene. The mixture freezes at -1.5°C. What is the molality of the solution?

$$\text{Since } \Delta T = K_F \cdot m \text{ it follows that } m = \frac{\Delta T}{K_F} = \frac{(5.5^\circ\text{C} - (-1.5^\circ\text{C}))}{\left(5.12 \frac{^\circ\text{C} \times \text{kg}}{\text{mol}} \right)} = \frac{7.0^\circ\text{C}}{\left(5.12 \frac{^\circ\text{C} \times \text{kg}}{\text{mol}} \right)} = 1.4 \frac{\text{mol}}{\text{kg}} \text{ where } K_F \text{ for benzene}$$

was found from the above table. It follows that:

$$\text{moles of solute} = (\text{kg solvent}) \times (\text{mol solute}) = (0.500 \text{ kg})(1.4 \text{ mol/kg}) = 0.70 \text{ mol solute}$$

The moles of solute can be used to determine the molar mass of a solute.

Sample Calculation 3

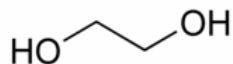
The solute in Sample Calculation 2 has a mass of 35 g. What is its molar mass?

The molar mass of a compound is its mass in 1 mole.

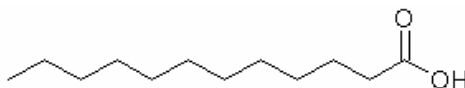
$$\text{MM} = \frac{\text{mass(g)}}{\text{moles}} = \frac{35 \text{ g}}{0.70 \text{ mol}} = 50 \frac{\text{g}}{\text{mol}}$$

A possibility for the solute is: C_5H_8

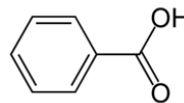
Freezing point depression is a useful phenomenon. The temperature range that cooling systems in cars operate is expanded by adding ethylene glycol to water. This is one reason that cars can operate in temperatures below 0°C. In this experiment we will use the freezing point depression of lauric acid to determine the molar mass of the solute benzoic acid.



ethylene glycol
(component in antifreeze)



lauric acid



benzoic acid

Procedure

SAFETY PRECAUTIONS

Proper eye protection must be worn throughout this experiment. The wires for temperature probes must be kept away from the hot plate.

Students work in groups of 2-3, depending on the availability of computer workstations.

1. Prepare a sample of pure lauric acid. Obtain about 8 g of lauric acid and place it in a clean dry test tube. Use a pen to label the test tube as the lauric acid.
2. Prepare a mixture of lauric acid and benzoic acid. Obtain about 8 g of lauric acid and place it in a second clean dry test tube. Record the mass of the lauric acid in the Data Sheet. Add about 1 g of benzoic acid to the lauric acid in this second test tube. Record the mass of the benzoic acid in the Data Sheet. Use a glass stirring rod to mix the two solids. Use a pen to label the test tube as the mixture.
3. Fill two 250 mL beakers with about 200 mL of tap water.
4. Place the two test tubes containing the solids into a 600 mL beaker containing about 400 mL of hot water. The temperature of the water should be between 65°C and 80°C. Allow both solids to fully melt.
5. Open the LoggerPro application. Select the folder **Chemistry with Computers**. Select the module titled **Freezing Point (Experiment 15)**.
6. If only one temperature is shown in the real time monitor select Experiment → Set up Sensors → Show all Interfaces. Click on CH2 and Choose Sensors → Stainless Steel Temperature. The realtime monitor should now show two temperature readings. To display both sensor readings on the graph double click on the graph and select Axes Options from the pop-up menu. Select Temperature 2.
7. Experimental parameters are controlled using the **Experiment** menu. Use the **Data collection** option in the **Experiment** menu to change the experiment length and sampling rate:

Mode = Timed Based

Sampling Rate = 15 samples/minute

Length = 10 minutes

Oversampling = Not Selected

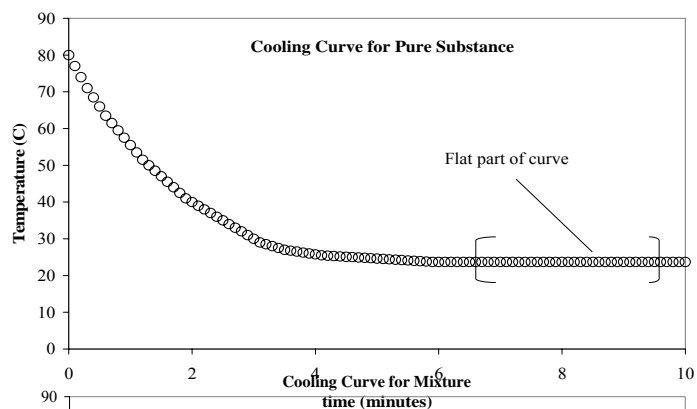
8. Select the vertical axis of the graph and change the temperature range to 20°C to 80°C.

9. If the solids are completely melted, then place the Channel 1 temperature probe into the test tube containing the lauric acid. Place the Channel 2 temperature probe into the test tube containing the lauric acid/benzoic acid mixture.

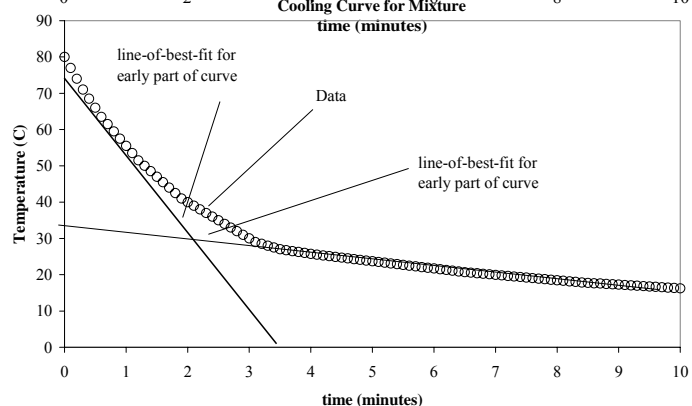
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10. Allow the temperature probes to equilibrate with the samples, meaning that the temperature should be stable. This may take a couple of minutes. Once they have equilibrated, begin collecting data by selecting the start function. The system will begin acquiring, recording, and displaying data on the graph screen.
 11. Once 30-60 seconds of data has been displayed on the screen pull the test tubes with the temperature probes out of the hot water bath and place each one into one of the 250 mL beakers containing room temperature water.
 12. Gently mix the samples by moving the temperature probes up and down slightly. Don't allow the temperature probes to move more than an inch up and down. Continue this motion until the samples begin to freeze.
 13. The instrument will stop acquiring data automatically at the end of the ten minute run.
 14. The experiment can be repeated, if necessary, by placing the test tubes back into the hot water and starting over.
 15. Once the experiment is successfully completed, place the test tubes with the probes in the hot water bath and allow the solids to melt. Once the solids have melted pull out the temperature probes and wipe them clean with a paper towel. The samples should be poured into a waste container provided or re-used by the next group.
 16. Save the data set to a 3 ½-inch diskette or USB flash drive before moving to the analysis of the graph.

Calculations

1. Determine the freezing point of the pure lauric acid. Pure substances freeze at a constant temperature. This temperature is found by taking the average (mean) of data from the flat part of the cooling curve. Select the flat section of the curve with the cursor and then select the **Statistics** option from the **Analysis** menu. The window should now display statistics for the region you selected, including the mean temperature. The mean temperature is the freezing point of the pure substance. Record this value in the Data Sheet.



2. The freezing point of the mixture requires a different method of analysis. The temperature of a freezing mixture is not constant, so taking the average temperature of a flat part of the cooling curve is not possible. To determine the freezing point of the mixture we need to draw two lines-of-best-fit and determine the temperature at which they intersect. One line-of-best-fit is drawn in the region of the dramatic initial decrease in temperature. The second line-of-best-fit is drawn in the approximately flat region near the end of the experiment. Each line-of-best-fit has a slope and y-intercept. The freezing point is the temperature at which the two lines intersect. The intersection of the two lines occurs at



$$y = \frac{b_1 m_2 - b_2 m_1}{m_2 - m_1} = T_{\text{FREEZING}} \quad \text{where } m_1 \text{ and } b_1$$

are the slope and y-intercept for the first line and m_2 and b_2 are the slope and y-intercept for the second line.

The linear fits are determined by using the curve fitting option in the analysis menu. Once these fits are made and the intercept is determined, record the freezing point in the Data Sheet. Title the graph to give information concerning which materials were studied. Once the two cooling curves have been analyzed save the file to a diskette and print a copy of the graph (not the data) in Landscape mode.

3.

3. To determine the molar mass of the solute (benzoic acid) we need to use the mass of the benzoic acid and calculate the number of moles of benzoic acid in the mixture because:

$$\text{molar mass} = \frac{\text{mass(g)}}{\text{moles}} = \frac{\text{mass of benzoic acid}}{\text{moles of benzoic acid}} \quad \begin{array}{l} \leftarrow \text{measured directly} \\ \leftarrow \text{calculated from FPD} \end{array}$$

The mass of the benzoic acid in the mixture was measured and is reported in the data sheet. The moles of benzoic acid can be determined from the freezing point depression.

4. Use the freezing points of the two solids to determine ΔT :

$$\Delta T = T_{F, \text{ pure}} - T_{F, \text{ mixture}}$$

The freezing point depression $\Delta T = K_F \cdot m$ where K_F is the molal freezing point depression constant and m is the molality of the solute.

Molality is defined as : $m = \frac{\text{moles solute}}{\text{kg solvent}}$

Rearrangement gives: $\text{mol solute} = (m) \times (\text{kg solvent})$ where kg of solvent is the mass of the solvent (lauric acid) in the mixture. This gives the moles of the solute. The mass of the lauric acid was measured in grams so a conversion to kilograms must be made (1 kg = 1000 g).

6. By combining the mass of the solute (measured) and the moles of solute (calculated in step 5) we can calculate the molar mass of the solute.

7. The molecular formula for benzoic acid is $C_7H_6O_2$. From this formula we can calculate the molar mass and compare it to the experimentally determined result from step 6 in the calculations.

$$\% \text{ difference} = \frac{MM_{\text{formula}} - MM_{\text{experimental}}}{MM_{\text{formula}}} \times 100 \quad \text{where MM is the molar mass.}$$

Questions

1. Why does the addition of benzoic acid lower the freezing point of lauric acid?
2. What would you expect to happen to the boiling point of lauric acid when benzoic acid is added? Explain.
3. How many grams of benzoic acid would be needed to lower the freezing point of 50 g of lauric acid by 3.5°C ?
4. What mass of benzoic acid would be required to lower the freezing-point of 1 kg of lauric acid by 25°C ? Is this practical? Explain.
5. The freezing point of pure lauric acid is between 44°C and 46°C . Compare the freezing point you measured with this range. Was your value higher, the same, or lower?
6. Draw a rough phase diagram for lauric acid, labeling the melting point and boiling point from the data in the discussion. Then draw a rough phase diagram for the case that a solute has been added to the lauric acid.
7. Write a one-page discussion of your results. What were they? Are they reasonable? Why or why not?

Observations and Notes

Date _____

Data Sheet
Experiment 12: Freezing Point Depression

Name _____

Date _____

Mass of lauric acid in the mixture _____ g

Mass of lauric acid in the mixture _____ kg (1 kg = 1000 g)

Mass of benzoic acid _____ g

Calculations

All calculations should be clearly shown on a separate piece of paper.

T_F for pure lauric acid _____ °C

T_F for mixture (lauric acid + benzoic acid) _____ °C

Freezing point depression, ΔT _____ °C

Molality of benzoic acid _____ $\frac{\text{mol}}{\text{kg}}$

Moles of benzoic acid _____ mol

Molar mass (experimental) _____ $\frac{\text{g}}{\text{mol}}$

Molar mass (from formula) _____ $\frac{\text{g}}{\text{mol}}$

% difference _____

