

Colligative Properties

Introduction

Colligative properties are those properties of a solution that depend on the amount of a chemical species in solution, and not on the identity of the species in solution. Examples of these properties are boiling point elevation, freezing point depression, and osmotic pressure. In this experiment, you will study the second of these common examples using the solvent cyclohexane, C₆H₁₂. You may recall from your textbook that freezing point depression is described by the equation:

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

where ΔT_f is the **freezing point depression**, i is known as the **van't Hoff i factor**, K_f is the **freezing point constant of the solvent**, and m is the **molality of the solution**. The freezing point depression, ΔT_f , is the difference between the freezing point of the pure solvent and the freezing point of the solution. A solution of NaCl has an i factor of 2, a solution of MgCl₂ has an i factor of 3 and a solution of a non-dissociating substance like sugar would have an i factor of 1. Cyclohexane is chosen as the solvent in this experiment for two reasons. First, it is convenient to use because it freezes at a temperature just above the freezing point of water, and second because it has a large K_f value. Thus, the freezing point depression is large for even dilute solutions of this solvent.

During this experiment you will first measure the normal freezing point of cyclohexane in your experimental apparatus. This will be slightly below room temperature and thus will require the use of an ice bath. In the next part of the experiment you will measure the freezing point of a solution of cyclohexane with para-dichlorobenzene as a solute to determine the freezing point depression constant for cyclohexane. This will require the use of a colder salt-ice water bath. Finally, you will use the K_f that you have determined in Part II to find the molecular mass of an unknown.

Incidentally, the zero point of the Fahrenheit temperature scale is defined by the freezing point of pure water saturated with common salt. Fahrenheit's scale was based on the arbitrary points of the freezing point of salt water and the temperature of a man's blood. Fahrenheit originally planned to make twelve divisions of this temperature span, but settled on ninety-six for convenience of measurement.

As pre-laboratory preparation you should read Sections 14-8 and 14-9 in Petrucci et.al., 8th ed.

Safety: Wear your goggles throughout the entire experiment. Cyclohexane is extremely flammable. Absolutely NO flames of any kind can be used while this experiment is in progress. Use the fume hood as much as possible to reduce odors. WEAR YOUR GOGGLES!

Work in pairs throughout this laboratory assignment.

Each student must collect data and submit a separate report. The actual data analyses and the written reports must be done entirely independently of your lab partner or other students. Make sure that you avoid unauthorized collaboration and plagiarism. All suspected violations of the Code of Academic Conduct will be referred to Student Judicial Affairs.

Experimental Procedure

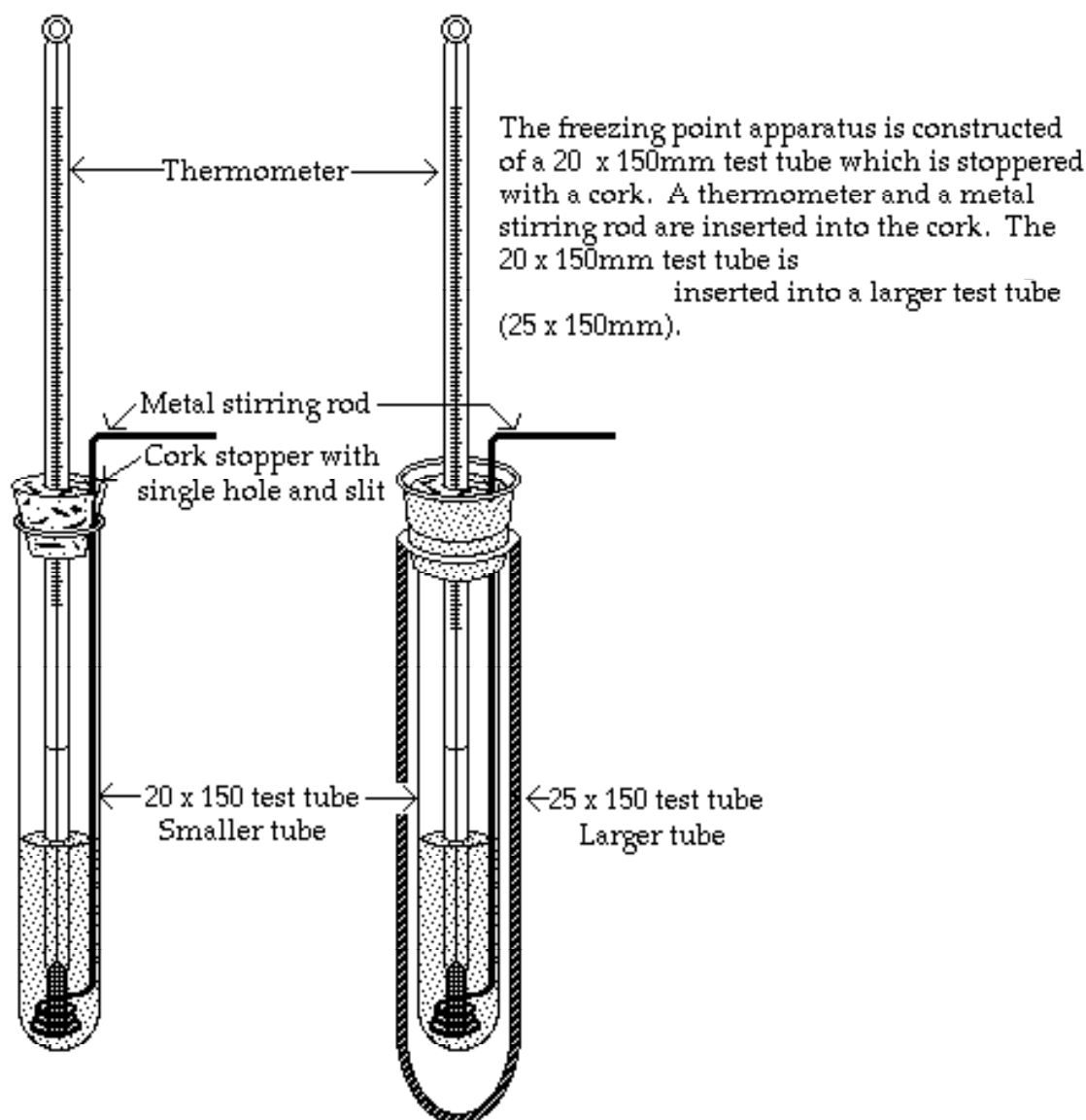
Part I. Determining the Freezing Point of Pure Cyclohexane

1. Make an ice-water bath in an 800 mL beaker, adding equal portions of ice and water. Ice may be found in a large bucket near the laboratory door. Obtain a freezing point apparatus found on the main supply shelf.
2. Using the 10 mL volumetric pipet accompanying the cyclohexane in the fume hood, accurately dispense 10.00 mL of cyclohexane into the smaller test tube of the apparatus. You must measure volume accurately so that mass of cyclohexane is known for the molality calculation in Part II. Using the known density of cyclohexane (0.7726 g/mL @ 25 °C), calculate the mass of cyclohexane measured.
3. Set up the apparatus as shown in Figure 1. Assemble the inner test tube of the apparatus with the cork, thermometer, and stirrer. Place the assembled inner test tube carefully into the larger test tube. The tape around the outer test tube forms a seal between the two. Mount your 800 mL beaker containing the ice-water bath onto a wire gauze and an iron ring.
4. Measure the temperature of the ice-water bath for later comparison in Part II. Record the temperature to the nearest 0.2 °C. Place the freezing point apparatus in the ice-water bath so that the cyclohexane is well below surface of the water. Clamp the freezing point apparatus in place. You will need to adjust your thermometer so that you can read the temperature scale between 0 and 10°C without the tape on the test tube interfering. In addition, the bulb of the thermometer must be well covered by the cyclohexane.
5. Measure the freezing point, by cooling the cyclohexane slowly to below room temperature using an ice-water bath. A good technique is for one student to carefully stir and read the thermometer while the other student records the temperature at regular intervals, say every 15 seconds. The correct freezing point is when the temperature stops decreasing, or plateaus. Be sure to raise and lower the

metal stirrer carefully to mix the sample thoroughly thereby maintaining a uniform temperature while it cools. Insufficient stirring will cause non-uniform cooling, and stirring too vigorously will cause the solution to splash and freeze on the side of the test tube. The outside surfaces of the test tube and beaker will have to be wiped with a paper towel periodically in order to accurately read the thermometer and see the sample.

6. Three or more trials need to be performed to obtain good precision in your measurements. (The melting points should be within $0.5\text{ }^{\circ}\text{C}$ of each other.) Freeze and melt the same sample for all trials. To save time, warm the sample in the palm of your hand to just above the melting point after each trial. Save the pure cyclohexane to use in Part II.

Figure 1: The Measurement of a Freezing Point



Part II. Determining the Freezing Point Constant for Cyclohexane

In this part of the experiment, you will collect data that will allow you to determine the K_f for cyclohexane. You can do this by adding a known quantity of solute to the cyclohexane solvent and measuring the freezing point of the mixture.

1. Allow the cyclohexane from Part I to warm to room temperature. Weigh out 0.5 – 0.6 g of *p*-dichlorobenzene, $C_6H_4Cl_2$. Record the mass to the nearest thousandth of a gram (0.001g). Carefully add the solid to the room-temperature cyclohexane. Stir the mixture until the *p*-dichlorobenzene is completely dissolved. This may take a few minutes. Reassemble the freezing point apparatus and stir the solution with the metal stirring rod to ensure complete mixing.
2. To measure the freezing point of the mixture, a salt-ice-water bath will be necessary. This bath can be prepared by filling an 800 mL beaker with alternating layers of ice and solid NaCl (~100 mL NaCl measured in a beaker); then add water to within two cm of the beaker rim. The salt-ice-water bath must be mixed well to achieve the sub-zero temperature needed for this part of the experiment. Measure the temperature of the ice-salt bath. The temperature of the salt-ice-water bath needs to be -10°C or lower.

TO AVOID BREAKAGE, DO NOT STIR THE SALT-ICE-WATER BATH WITH A THERMOMETER. USE A STIR ROD.

3. Clamp the freezing point apparatus into the salt-ice-water bath as in Part I. Here, the thermometer needs to be adjusted so that it is well submerged in the solution while allowing you to read the temperature scale between -8°C and 0°C without interference from the tape on the test tube. You will need to view the temperature scale through the walls of the test tubes. Again, work with your partner to record the decreasing temperature at regular intervals. As the solid begins to form, stir more slowly being sure to keep the thermometer bulb submerged in solution. As you approach the freezing point, the rate of cooling slows. Do not become impatient here, a plateau will occur. The sample will have to be frozen and melted three or more times until you obtain good precision in your measurements. When you thaw the solution, only allow it to warm about 5°C ABOVE its freezing point. If you let the solution return to room temperature between each trial, this experiment will take an inordinate amount of time.
4. After the data has been collected, pour the melted mixture into the appropriate waste bottle in the fume hood. Rinse out the smaller test tube, metal stirrer, and your thermometer with a few milliliters of cyclohexane. Place the cyclohexane rinse in the waste bottle as well. The larger test tube should not need cleaning. **Save the salt-ice-water bath for Part III.**

Part III. Determining the Molecular Mass of Solute

1. In part III, you will design an experiment to determine the molecular mass of an unknown substance. Your experimental design will be similar to the procedures used in part II. Some unidentified solutes are provided in the laboratory. There are mass ranges recommended on the bottles, since different solutes will require different masses. Furthermore, the solute may be slow to dissolve; however, complete dissolution is essential for molecular mass determination. **RECORD IN YOUR LABORATORY NOTEBOOK THE NUMBER OR LETTER OF THE UNKNOWN SOLUTE YOU USE.** Do not forget this step. You will need your solute number or letter for the laboratory write up.
2. You may need to refresh your salt-ice-water bath. The sample will have to be frozen and melted three or more times until you obtain good precision.

Clean-up

After the data has been collected, pour the melted mixture into the appropriate waste bottle in the fume hood. Rinse out the smaller test tube, metal stirrer, and your thermometer with a few milliliters of cyclohexane. Place the cyclohexane rinse in the waste bottle as well. The larger test tube should not need cleaning. The salt-ice-water bath may be poured in the sink with copious amounts of water.

Data Analysis

Parts I & II

1. In calculating K_f you must make an assumption about *p*-dichlorobenzene. What is that assumption?
2. Calculate the average freezing point of the pure cyclohexane.
3. Using the average freezing point of the cyclohexane, calculate the K_f of cyclohexane for each trial performed in part II.
4. Calculate an average K_f value.
5. Calculate the standard deviation of the average K_f value.
6. Calculate the 90% confidence limit of your data collected in part II.
7. Explain why salt is added to the ice-water bath in part II. Carefully explain how this works

Part III

8. In calculating the molecular mass of the unidentified solute, you must make an assumption about the solute. What is that assumption?
9. For each trial, calculate the freezing point depression, ΔT_f .
10. Using the freezing point depression, ΔT_f , calculate the molecular mass of the unknown solute, for each trial.
11. Calculate an average molecular mass of the unknown solute.
12. Calculate the standard deviation of the average value.
13. Calculate the 90% confidence limit of your data collected in part III.

Conclusion. Compose a few paragraph summary of this experiment. Include some comments about the sources of error in the experiment that may be responsible for the difference between the values you have obtained and the accepted literature values for the properties you studied in this experiment.