PROBEWARE INVESTIGATION 3 • A

Determining Molar Mass

[CAUTION]: This investigation should be done as a demo, or with a small group using the fume hood, due to the toxic fumes produced.

Dissolved substances depress the freezing points of liquids. The depression is characteristic of the liquid and dependent on 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:

$$\Delta T = K_f m$$

where:

ΔT is the change in the freezing point
K_f is the freezing point constant, different for each solvent (7.10°C/*m* for p-dichlorobenzene in this experiment)
m is the molality of the solute.

From the freezing point depression you can calculate the molality, and, ultimately, the molar mass of the solute.

Question

How can we determine the molar mass of a compound by using freezing points?

Prediction

Predict the molar mass of the naphthalene.

Materials

computer system and interface
temperature sensor
20.00 g p-dichlorobenzene ($C_6H_4Cl_2$)
1.00 g naphthalene ($C_{10}H_8$)
[CAUTION]: use naphthalene in the fume hood.
25 × 150 mm test tube
support stand
utility clamp
250 mL beaker
hot plate
water (for a hot water bath)

Safety Precautions

- Be sure the room is very well ventilated.
- This experiment must be done carefully to avoid burns and broken glass.
- Be sure to dispose of materials properly.

Procedure

Part 1

1. Set up the computer system with the temperature sensor.

2. Display the sensor with a graph (temperature vs. time) and digits display.

3. Place 20.00 g of p-dichlorobenzene (the solvent) into the clean dry test tube.

4. Fill the beaker ¾ full of water and bring it to a boil on the hot plate on the base of the support stand. Turn off the heat source.

5. Clamp the test tube and contents into the utility clamp.

6. Lower the test tube and contents into the hot water bath and clamp this to the support stand.

7. Set the sensor to monitor temperature, insert the temperature sensor into the test tube, and continuously stir the sample of p-dichlorobenzene with it (hold the top of the sensor, not its wire).

8. After the p-dichlorobenzene has melted and its temperature has reached about 70°C, stop the temperature monitoring.

9. Raise the utility clamp and test tube out of and away from the hot water bath and start the temperature data recording for Run #1.

10. Continuously stir the contents of the p-dichlorobenzene as it cools.

11. Continue recording the temperature of the p-dichlorobenzene as the temperature drops and the temperature forms a more horizontal line on the graph (about 8 minutes).

12. After 2 additional minutes, stop recording the data for Run #1.

13. Place the test tube and p-dichlorobenzene back into the hot water bath and turn on the heat source.

14. Monitor the temperature of the p-dichlorobenzene again.

15. Once the p-dichlorobenzene has again melted completely and reached 70°C, remove the temperature sensor and add the 1.00 g of naphthalene.

16. Return the temperature sensor to the test tube and continue stirring.

17. Once the temperature has increased to 70°C, raise the utility clamp and test tube out of and away from the hot water bath, and start the temperature data recording for Run #2.

18. Continuously stir the contents of the p-dichlorobenzene / naphthalene solution as it cools.

19. Continue recording the temperature of the p-dichlorobenzene/naphthalene solution as the temperature drops and the temperature forms a more horizontal line on the graph (about 8 minutes).

20. After 2 additional minutes, stop recording the data for Run #2.

21. When the reaction is complete, re-melt the contents of the test tube, remove the thermometer sensor, and dispose of the p-dichlorobenzene / naphthalene solution into an organic waste container or as directed by your teacher. Do not pour anything down the drain. Wash your hands. **Note**: This step should be done by the teacher to ensure safety.

Analysis

1. From the graph of the cooling behaviour of the solvent p-dichlorobenzene (Run #1), draw a straight line that follows the initial drop in temperature before it begins to rise or level out.

2. Draw a second straight line along the flat plateau part of the curve where freezing began.

3. What is the temperature listed at the intersection of the two lines? This will be $T_{\text{f, solvent}}$.

4. Repeat the above three steps for the second graph of the p-dichlorobenzene / naphthalene solution (Run #2). This will be $T_{\text{f, solution}}$.

5. Calculate the freezing point depression $\Delta T = T_{\text{f, solvent}} - T_{\text{f, solution}}$

6. Using ΔT from above, and K_f = 7.10°C/m for p-dichlorobenzene, calculate the molality (m) of the solute naphthalene using

$$m_{\text{solute}} = \frac{\Delta T}{K_f}$$

7. Find the number of moles of solute by multiplying the molality of the solvent by the mass used (in kilograms).

moles of solute = m_{solute} × #kg of solvent

8. Find the molar mass of the solute by dividing the mass of the solute, in grams, by the number of moles of solute:

$$\text{molar mass of solute} = \frac{\text{mass of solute}}{\text{moles of solute}}$$

9. What is the percent difference between the molar mass of solute you measured and the actual molar mass of naphthalene (128 g/mol)?

10. How might you account for this difference?

Conclusions

11. Write a conclusion to explain how your experimental observations supported your calculations.

Applications

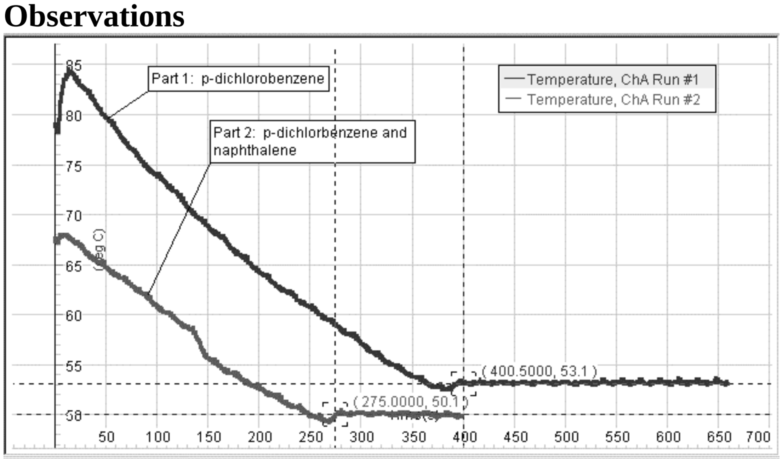
12. Describe what is happening at the "dip" in the cooling curves?

13. The freezing point of p-dichlorobenzene is 53°C. What is the % relative error in your result?

Teacher Information

Sample Data – Answer Sheet

Observations



Graph 1

Answers

3. $T_{\text{f, solvent}}$ = 53.1°C

4. $T_{f,\ solution} = 50.1°C$

5. $\Delta T = 53.1 - 50.1$
$\Delta T = 3.0°C$

6. $m_{solute} = \dfrac{3.0}{7.10}$
$m_{solute} = 0.423$ mol/kg

7. moles of solute =
0.423 mol/kg × 0.020 kg
moles of solute = 0.00845 mol

8. molar mass of solute = $\dfrac{1.00\ \text{g}}{0.00845\ \text{mol}}$
molar mass of solute = 118.3 g/mol

9. 7.6%

10. Inaccurate massing, evaporation of materials, limited runs, purity of materials, consistency of stirring, the temperature sensor might need calibration, or inaccuracy of graph measurements.

12. Often solutions tend to undercool. That is, they cool to a temperature below the freezing temperature before crystal formation begins. When crystallization begins, the temperature suddenly rises. This sudden change in temperature is due to the release of thermal energy — the heat of crystallization.

13. Answers will vary.