

Mr. Feebeck
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well done

Lab: Using Freezing-Point Depression to Find Molecular Weight

I. Introduction/Purpose

Colligative properties are properties which depend only on the number of solute molecules present in a solution and include freezing point depression, boiling point elevation, vapor pressure lowering, and osmotic pressure. The equation for freezing point depression relates the property with a pre-determined constant K and molality, which is expressed in moles of solute per kilograms of solvent. The equation is:

$$\Delta T = K_f \cdot m$$

The following experiment utilizes the relationship between freezing point depression and molality to find the molecular weight of a particular solution. By comparing the freezing points of pure lauric acid and a lauric acid-benzoic acid mixture, the freezing point depression and molality can be found, and the molecular weight of benzoic acid can be determined from the molality of the solution.

II. Materials

computer	utility clamp
Vernier computer interface	18 x 150 mm test tube
Logger Pro	lauric acid
Temperature probe	benzoic acid
400 mL beaker	thermometer
ring stand	

optional for reference lab (citation)

III. Procedure

The procedures for this experiment were outlined in the lab "Using Freezing-Point Depression to Find Molecular Weight" from *Chemistry with Vernier*.

Before beginning the experiment, safety goggles were worn. The temperature probe was prepared by plugging it into the computer and opening up the corresponding lab file on the Vernier computer interface.

III. A. Determination of Freezing Points

In Part I of the experiment, 300 mL of room temperature water was added to the beaker, which was then placed in the ring stand. A sample of lauric acid in a test tube was obtained, and the temperature probe was placed into the sample. After waiting about 30 seconds for the probe's

temperature readings to stabilize, the Vernier software began collecting and graphing temperature readings. However, if the lauric acid's initial temperature was not above 50°C, the lab instructions called for a new sample. The lauric acid was continuously stirred with the probe for 10 minutes.

After data collection stopped at 10 minutes, the test tube was placed in a hot water bath to melt the probe out. In order to find the freezing temperature of the pure lauric acid, the average of the portion of the graph with nearly constant temperature was taken. The mean temperature was then recorded as the freezing temperature of pure lauric acid.

In Part II of the experiment, the procedure of Part I was repeated, but instead of pure lauric acid, a sample containing about 1 gram of benzoic acid and 8 grams of lauric acid was used. The same steps used in Part I were used to determine the freezing point of the benzoic acid and lauric acid mixture. However, instead of using the average of the flat portion of the temperature vs. time graph, only the initial freezing temperature was used as the freezing point. The change in procedure was due to the gradual linear decrease in temperature during the time when the benzoic acid and lauric acid mixture was freezing.

III. B. Analysis of Data/Determination of Molecular Weight

To determine the experimental molecular weight of benzoic acid, the freezing temperature depression, the molality of the solution, and the moles of benzoic acid were determined through calculations. The experimental molecular weight was then compared to the accepted molecular weight of benzoic acid.

IV. Data/Observations

Table 1: Masses of acid samples

Mass of lauric acid	8.032 g (pure lauric acid sample) 7.997 g (mixture sample)
Mass of benzoic acid	1.029 g

Table 2: Freezing points of acid samples

Freezing temperature of pure lauric acid	42.87°C
Freezing point of benzoic acid-lauric acid mixture	39.7°C

Due to the size of the temperature probe and test tube, the lauric acid and benzoic acid-lauric acid mixture could not be stirred by the probe without the probe hitting the test tube glass. Also, at the end of the 10 minutes of data collection, both the samples still had not frozen completely.

Table 3: Values to determine experimental molecular weight of benzoic acid

Freezing temperature depression, Δt	3.17°C
Molality, m	0.81 mol/kg

Moles of benzoic acid	0.0065 mol
Molecular weight of benzoic acid (experimental)	158.3 g/mol
Molecular weight of benzoic acid (accepted)	122.1 g/mol
Percent error	29.63%

Table 4: Class values for experimental molecular weight of benzoic acid

Group	Experimental molecular weight (g/mol)
1	90.06
2	115.5
3	158.3
4	154.1
5	124.2
6	195.19
7	111.31

Table 5: Absolute error, average deviation, relative average deviation, standard deviation, and mean of class results

Absolute error	36.19 g/mol
Average deviation	28.86 g/mol
Relative average deviation	0.2130
Standard deviation	35.61 g/mol
Mean	135.5 g/mol

V. Analysis/Calculations

Freezing temperature depression

$$\Delta t = t_1 - t_2 = 42.87 - 39.7 = 3.17^\circ\text{C}$$

Molality

$$\Delta t = K_f \cdot m$$

$$m = \frac{\Delta t}{K_f} = \frac{3.17^\circ\text{C}}{3.9^\circ\text{C} \cdot \text{kg/mol}} = 0.81 \text{ mol/kg}$$

Moles of benzoic acid

$$\frac{0.81 \text{ mol}}{1 \text{ kg}} \cdot (0.007997 \text{ kg}) = 0.0065 \text{ mol}$$

Molecular weight of benzoic acid (experimental)

$$\frac{1.029 \text{ g}}{0.0065 \text{ mol}} = 158.3 \text{ g/mol}$$

Molecular weight of benzoic acid (accepted)

Benzoic acid: C_6H_5COOH

$$\text{Molecular weight} = 6(12.01) + 5(1.008) + 12.01 + 16 + 16 + 1.008 = 122.1 \text{ g/mol}$$

Percent error

$$\% \text{ error} = \frac{|value_{calc.} - value_{accepted}|}{value_{accepted}} \times 100 = \frac{|158.305 - 122.118|}{122.118} \times 100 = 29.63\%$$

Absolute error

$$\text{Absolute error} = value_{calc.} - value_{accepted} = 158.305 - 122.118 = 36.19 \text{ g/mol}$$

Average deviation

$$\bar{d} = \frac{\sum_{i=1}^n |x_i - \bar{x}|}{n} = \frac{\sum_{i=1}^7 |x_i - 135.523|}{7} = 28.86 \text{ g/mol}$$

Relative average deviation

$$r. a. d. = \frac{av. deviation}{av. measured value} = \frac{\bar{d}}{\bar{x}} = \frac{28.86}{135.523} = 0.2130$$

Standard deviation

$$\sigma = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n - 1}} = \sqrt{\frac{\sum_{i=1}^7 (x_i - 135.523)^2}{6}} = 35.61 \text{ g/mol}$$

Mean

$$\text{Mean} = \frac{\sum_{i=1}^n x_i}{n} = \frac{948.7}{7} = 135.5 \text{ g/mol}$$

VI. Results and Discussion

The experiment showed the relatively high freezing point of lauric acid, particularly when compared to water's freezing point at 0°C . The experiment also exemplified the concept of freezing point depression, and a significant freezing point depression of 3°C was seen with the addition of only approximately 1 gram of benzoic acid to approximately 8 grams of lauric acid. Even with such a low amount added, benzoic acid was shown to have a noticeable effect on the freezing point of lauric acid.

Class results for the experimental molecular weight of benzoic from Table 4 showed a wide range of experimental values, resulting in the relatively high deviations seen in Table 5. The individual group result for this experiment also resulted in a nearly 30% error, as seen in Table 3.

The variety of results, high deviations, and individual group error indicate that the experiment may not have been performed with consistency.

VII. Conclusion

Overall, the results of the experiment supported the expected outcome. Although the individual group result seemed highly inaccurate at first, it still provided a general overview of the method to obtain molecular weight from freezing point depression. The concept of freezing point depression was also clearly displayed as a minimal amount of benzoic acid decreased the freezing point of lauric acid.

One potential source of error is in the determination of the freezing point. Although for pure lauric acid the average of the portion of the graph when the solution was freezing was used, determining which part of the graph to use was difficult. Due to the gently sloping nature of the graph, there was no clear start and end point of the plateau on the temperature vs. time graph. The freezing point of the benzoic acid-lauric acid mixture was also difficult to determine because of the sloping nature of the graph. Although typical cooling curves show a sharp initial freezing point, no such point existed on the created graph, making it difficult to determine a freezing point for the solution.

Another source of error concerned the solutions. Although great care was taken to prevent any solution from leaving the test tube, when the temperature probe was melted out of the solid acid, slight traces of acid inevitably remained on the probe and had to be removed with a paper towel. The amount was miniscule and likely insignificant, but repeated use of the solutions by different groups could have caused a more significant change in the mass of the solution, which would have affected the determination of moles of benzoic acid and the subsequent calculation of the molecular weight.

If the experiment were to be repeated, using a wider test tube which would allow the solutions to be stirred without interference could prevent any slight variations in temperature readings caused by the probe hitting the test tube.

excellent

Label?

Latest		
Time (min)	Temperature (°C)	Time (min)
318	38.6	
319	38.6	
320	38.5	
321	38.5	
322	38.4	
323	38.4	
324	38.4	
326	38.4	
326	38.3	
327	38.3	
328	38.2	
329	38.2	
330	38.2	
331	38.2	
332	38.2	
333	38.2	
334	38.2	
335	38.1	
336	38.1	
337	38.1	
338	38.1	
339	38.1	
340	38.1	
341	38.1	
342	38.2	
343	38.2	
344	38.2	

Temperature
30.6 °C

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