LEARNING OBJECTIVES

The learning objectives of this experiment are to

- explore the relationship between the temperature and vapor pressure of water.
- determine the molar heat of vaporization of H\textsubscript{2}O.

BACKGROUND

The molar heat of vaporization of water, $\Delta H_{\text{vap}}$, is defined as the amount of heat needed to convert a mole of liquid water to water vapor at the boiling point and one atmosphere pressure. It is possible to estimate the heat of vaporization by measuring the vapor pressure of water at different temperatures using the method described below.

Approximately 2 mL of air is trapped in an inverted graduated cylinder immersed in a water bath. The water bath is cooled to a temperature close to 0\(^\circ\)C and then allowed to warm gradually. As heating takes place, temperature and volume measurements are recorded. The number of moles of water vapor in the gas phase changes with temperature, but the amount of "trapped" air remains constant, assuming there is a negligible change in the solubility of air in water as temperature changes.

If the number of moles of "trapped" air in the inverted cylinder ($n_{\text{air}}$) is known, the partial pressure of air ($P_{\text{air}}$) can be calculated at each temperature. When this value is subtracted from the atmospheric pressure, the vapor pressure of the water $P_{\text{H}_2\text{O}}$ at each temperature will be obtained.

$$P_{\text{H}_2\text{O}} = P_{\text{atm}} - P_{\text{air}}$$

Equation 1.

The number of moles of air, $n_{\text{air}}$, can be found by measuring the volume, temperature, and pressure of the trapped gas at a temperature near 0\(^\circ\)C, where the water vapor content is less than one percent and can be neglected.

$$n_{\text{air}} = \frac{P_{\text{atm}} V_1}{R T_1}$$

Equation 2.
The molar heat of vaporization can be estimated by means of the Clapeyron equation.

\[
\ln(P_{H_2O}) = \left(\frac{-\Delta H_{vap}}{R}\right) \frac{1}{T} + C
\]

where

- \(P_{H_2O}\) is the vapor pressure of water
- \(T\) is the absolute temperature
- \(R\) is the gas constant, 8.3145 J mol\(^{-1}\) K\(^{-1}\)

and \(C\) is a constant that depends on the particular liquid.

The vapor pressure is determined at a series of temperatures. \(\ln(P_{H_2O})\) is plotted against \(1/T\) to give a straight line with a slope equal to \(-\Delta H_{vap}/R\).

**SAFETY PRECAUTIONS**

Safety goggles must be worn at all times in the lab.

**EXPERIMENTAL PROCEDURE**

1. Using two rubber bands fasten the temperature probe to the 10 mL graduated cylinder as shown in Figure 1. Leave about 1.5 cm between the tip of the thermometer and the opening of the tube. Make sure the rubber bands are not placed between the 1.6 and 7.0 mL markings so as to not obscure any volume readings.

![Temperature probe](image)

**Figure 1.**
2. Place about 300 mL of crushed ice in the large beaker and then fill it up with distilled water to about 500 mL. Stir the slush mixture until the temperature has dropped to approximately 0°C and then remove any excess ice. Place the beaker on the hot plate but do not turn the heat on yet!

3. Fill the graduated tube with distilled water until it is about 2 cm from the top. Cover the top with your finger and invert to see if the air space is 2.2 mL. Adjust by adding or taking out some water until the space is about 2.2 mL.

4. Cover the top with your finger and invert the tube. Submerge the filled graduated cylinder in the large beaker filled with ice water and remove your finger. An air sample of about 2 mL should be trapped. Clamp the thermometer to the ring stand, making sure the tube is submerged and resting near the bottom of the beaker. Add more water to the beaker, if necessary, until the bath water level is more than 1 cm above the inverted tube. This is done to ensure that the trapped air in the tube is surrounded by water.

5. Turn on the stir bar and stir gently. Take a volume reading of the trapped air when the temperature is near 0°C. If the temperature is not near 0°C, add more ice to bring the temperature down. Make sure you are reading the bottom of the water meniscus.

6. Turn hot plate on and warm water gradually. Record temperature and air volume measurements often. Continue until temperature reaches approximately 80 °C.

7. Obtain the barometric pressure reading (P atm) and record.

**DATA ANALYSIS**

1. Use Equation (2) to calculate the number of moles of "water less" air (n air). The temperature and volume readings needed are those obtained for the first data point (V 1 and T 1); R = 0.08206 L atm mol⁻¹ K⁻¹.

   **Note:** for each volume reading, one must subtract 0.15 mL to correct for the inverted meniscus.

2. In a Spreadsheet, calculate P H₂O, according to Equation (1). Note that P air depends on temperature, and is determined by means of Equation (2). The formula used for this calculation, P H₂O = P atm - P air, must include the corrected volume in liters and temperature in Kelvin.

3. Plot a linear regression graph of ln (P H₂O ) (column F) versus 1/T (column G).

4. From the slope of your line determine ΔH vap for H₂O. (slope = -ΔH vap/(8.314 J K⁻¹ mol⁻¹))
5. Use the following literature values to calculate $\Delta H_{\text{vap}}$ for $\text{H}_2\text{O}$. These are from the CRC Handbook, 70th edition. Make sure to convert pressure to atmospheres.

<table>
<thead>
<tr>
<th>Temperature $\text{Celsius}$</th>
<th>$P_{\text{H}_2\text{O}}$ mmHg</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4.579</td>
</tr>
<tr>
<td>5</td>
<td>6.543</td>
</tr>
<tr>
<td>10</td>
<td>9.209</td>
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<tr>
<td>15</td>
<td>12.788</td>
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<td>20</td>
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<td>25</td>
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<td>35</td>
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<td>70</td>
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<tr>
<td>75</td>
<td>259.1</td>
</tr>
<tr>
<td>80</td>
<td>355.1</td>
</tr>
</tbody>
</table>
Data Sheet

Data needed to calculate moles of “waterless air”:

Barometric pressure reading \((P_{\text{atm}})\) \_________ atm

Lowest temperature reading \((T_1)\) \_________ K

Initial volume at lowest temp \((V_1)\) \_________ L

Moles of “water less” air (see Eq. 2) \_________ moles

Set up excel spreadsheet as follows:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>Temperature</td>
<td>Temperature</td>
<td>Corrected Volume</td>
<td>(P_{\text{H}_2\text{O}})</td>
<td>(\ln(P_{\text{H}_2\text{O}}))</td>
<td>1/Temperature</td>
</tr>
<tr>
<td>(\text{mL})</td>
<td>(^{\circ}\text{C})</td>
<td>K</td>
<td>L</td>
<td>atm</td>
<td>none</td>
<td>(\text{K}^{-1})</td>
</tr>
</tbody>
</table>

In your results make sure to report the following:

\(\Delta H_{\text{vap}}\) for water (literature value) \_________

\(\Delta H_{\text{vap}}\) for water (experimental value) \_________

\(\Delta H_{\text{vap}}\) for water (ave. class experimental value) \_________
Chemistry 212

Pre Laboratory Questions

VAPOR PRESSURE OF WATER

Calculate the theoretical $\Delta H_{\text{vap}}$ for water from the given literature values. You will need to do this in excel, graph $\ln (P_{\text{H}_2\text{O}} \text{ (atm)})$ vs. $1/ (T \text{ (K)})$. Look up the conversion factor for converting mmHg to atm. *Attach the printed excel graph.*