PHYSICAL CHEMISTRY LABORATORY

MOLECULAR WEIGHT OF A VAPOR

FINAL REPORT

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SECTION 1, GROUP 1a
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ABSTRACT

The molecular weight of ethyl acetate was determined in this experiment using a formula derived from the ideal gas law and experimental measurements of mass, volume, temperature and pressure of the sample. The molecular weight was determined to be 50 g/mol +/- 10% (RSD). This value compares unfavorably to the literature value of 88 g/mol [1].

RESULTS AND DISCUSSION

The experiment was performed using a Corning hotplate, a Mettler analytical balance, mercury-filled barometer and thermometer, a 100mL round-bottom flask (rbf), and miscellaneous pieces of common lab equipment, supplies, and glassware.

The volume of the rbf was determined by first obtaining the mass of the empty flask sitting on a cork ring (for stability) using an analytical balance. Fingerprint masses were avoided by using gloves to handle the rbf. After recording the empty rbf mass (and cork ring), the flask was then carefully filled with distilled water until the top of the water meniscus was just above the top of the rbf. This level was decided to most accurately represent the volume of the flask. Finally, the empty mass was subtracted from the filled mass to obtain the mass of the water it took to fill the flask (Equation 1).

\[ m_{H_2O} = m_f - m_i \]  
\[ = 155.4046g - 54.9135g \]  
\[ = 100.4911g \]

Where \( m_{H_2O} \) is the mass of distilled water to completely fill the rbf  
\( m_f \) is the mass of the distilled water, the rbf, and the cork ring  
\( m_i \) is the mass of the rbf and cork ring

The temperature of the water was found using a mercury thermometer. The volume of the rbf was calculated using the temperature and the density of water (Equation 2).

\[ V_{rbf} = V_{H_2O} = \frac{m_{H_2O}}{\rho_{H_2O}} \]  
\[ = \frac{100.4911g}{0.99701g/mL} \]  
\[ = 100.79mL \]

Where \( V_{rbf} \) is the volume of the rbf (equiv. to the volume of the water contained by the rbf)  
\( \rho_{H_2O} \) is the density of pure water at 21°C, corrected for buoyancy (0.99701g/mL) [1]  
\( m_{H_2O} \) is the mass of the water
A 400mL beaker of water was heated to boiling. The temperature of the water bath was measured with a mercury thermometer to $\pm 0.1^\circ C$. The temperature was carefully obtained from a mid-point in the boiling water bath rather than close to the sides or bottom of the beaker. Also, the barometric pressure was obtained to $\pm 0.01cm Hg$. Unit conversions are shown in Equations 3 and 4.

$$T_{vapor} = T_{H2O Bath} = 99.7^\circ C = (99.7 + 273.15)K = 372.85K \quad [4]$$

$$P_{vapor} = P_{atm} = 74.19cm Hg = (1atm/76.00 \text{ cm Hg}) = 0.9762atm \quad [4]$$

The rbf was then emptied and dried using a small amount of acetone. It was shaken several times to hasten the drying. Next, a circle was drawn on the bottom of the rbf that was approximately the diameter of $\frac{1}{2}$ of a dime. A quarter-size (~10 drops using a Pasteur Pipet) amount of ethyl acetate was added to the flask, then it was covered with a small (~1.25in$^2$) piece of aluminum foil. To insure that the vapor was at atmospheric pressure and to allow the excess volume of vapor to escape, a small hole was pushed into the foil with a pin. Finally, the rbf was attached to a ring stand via a round-jaw clamp and lowered into the boiling water bath.

The flask was submerged as deeply as possible in the 100mL flask to ensure uniform temperature of the vapor. After a few minutes, the solvent started to evaporate. When the solvent's surface area reached the size of the circle drawn on the bottom of the flask, it was removed from the hot water. This small amount of residual liquid appeared to vaporize during the process of removing it from the water bath.

Once the flask cooled, the aluminum foil cap was removed and the outside of the flask was quickly dried. Using the same balance and cork ring, the mass of the flask was soon determined. Again, fingerprint masses were avoided by wearing gloves. The mass was found by difference (Equation 5):

$$m_{vapor} = m' - m_f$$

$$= 100.6580g - 100.4911g = 0.1669g$$

Where $m_{vapor}$ is the mass of ethyl acetate vapor
$m'_f$ is the mass of the rbf, cork ring, and vapor
$m_f$ is the mass of the rbf and cork ring

Finally, the vapor masses were converted to MW (Equation 6):

$$M_w = \frac{mRT}{PV} = \frac{(0.1669g)(82.057 \frac{cm^3 \cdot atm}{mol \cdot K})(372.85K)}{(0.9762atm)(100.79cm^3)}$$

$$= 51.90g/mol$$
Where \( M_w \) is the molecular weight of ethyl acetate
\( m \) is the mass of the condensed ethyl acetate vapor
\( R \) is the ideal gas constant [3]
\( T \) is the temperature of the vapor
\( V \) is the volume of the ethyl acetate vapor
\( P \) is the pressure of the ethyl acetate vapor

Using this same method, molecular weights were calculated for all of the trials.

### TABLE I: Data and Results [4]

<table>
<thead>
<tr>
<th>TRIAL</th>
<th>( m' ) (g)</th>
<th>( m_{vapor} ) (g)</th>
<th>( M_w ) (g/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>55.0804</td>
<td>0.1669</td>
<td>51.90</td>
</tr>
<tr>
<td>2</td>
<td>55.0832</td>
<td>0.1697</td>
<td>52.77</td>
</tr>
<tr>
<td>3</td>
<td>55.1130</td>
<td>0.1995</td>
<td>62.04</td>
</tr>
<tr>
<td>4</td>
<td>55.0817</td>
<td>0.1682</td>
<td>52.30</td>
</tr>
<tr>
<td>5</td>
<td>55.0548</td>
<td>0.1413</td>
<td>43.94</td>
</tr>
</tbody>
</table>

### Error Analysis

1. Accuracy

a) Mean

\[
\bar{x} = \frac{\sum_{i=1}^{N} x_i}{N}
\]

\[
= \frac{(51.90 \text{ g/mol} + 52.77 \text{ g/mol} + 62.04 \text{ g/mol} + 52.30 \text{ g/mol} + 43.94 \text{ g/mol})}{5}
\]

\[
= 52.59 \text{ g/mol}
\]

b) Absolute Error

\[
E_{\text{Absolute}} = |x_{\text{EXPERIMENT}} - \bar{x}_1|
\]

\[
= |52.59 \text{ g/mol} - 88.11 \text{ g/mol}| = |-35.52 \text{ g/mol}| = 35.52 \text{ g/mol}
\]

c) Relative Error
\[ E_{\text{Relative}} = \frac{E_{\text{Absolute}}}{X_T} \times 100\% \]  
\[ = (35.52/88.11) \times 100\% = 40\% \]  

2. Precision  

a) Standard Deviation (Equations 10-13)  
\[ |x_i - \bar{x}| = |51.90g/mol - 52.59g/mol| = |-0.69g/mol| = 0.69g/mol \]  
\[ |x_i - \bar{x}|^2 = |-0.69g/mol|^2 = 0.4761g^2/mol^2 \]  
\[ \sum_{i=1}^{N} |x_i - \bar{x}|^2 \]  
\[ = |-0.691g/mol|^2 + |0.180g/mol|^2 + |9.45g/mol|^2 + |-0.286g/mol|^2 + |8.65g/mol|^2 = 164.67g^2/mol^2 \]  
\[ s = \sqrt{\frac{\sum_{i=1}^{N} |x_i - \bar{x}|^2}{N-1}} \]  
\[ = \sqrt{\frac{164.67g^2/mol^2}{4}} = 6.0g/mol \]  

b) Relative Standard Deviation  
\[ \text{RSD} (%) = \frac{SD}{\text{Mean}} \times 100\% = 6g/mol/52.59g/mol \times 100\% = 10\% \]
CONCLUSION

The molecular weight (MW) of ethyl acetate was determined to be 50 g/mol +/- 10% (RSD). This value is greater than 35g/mol (40%) less than the literature value of 88 g/mol [5]. Two of the trials (3 & 5) were significantly different from the other three and contributed significantly to the lack of precision. Since there was no justification to disregard the data, it was included in the results.

The poor precision was more than likely the result of several problems within the procedure we followed. It was difficult to consistently evaporate the liquid ethyl acetate (it was difficult to decide, even with a circle on the bottom of the flask, when to remove the flask from the bath). Also, the aluminum foil may have sometimes been removed too soon (before the flask was cooled and all of the vapor was condensed), also contributing to problems with reproducibility.

There are more than likely many contributors to the poor accuracy. The assumption that the temperature of the vapor was equivalent to the boiling water (bath) was probably a good one, since a lower temperature would have decreased the molecular weight. However, it’s possible the thermometer was inaccurate and should have been calibrated for more exact work. The barometric pressure was assumed to remain constant during the four hours of lab. This may have contributed to the error since a decrease in the pressure would have meant a higher molecular weight. The volume of the flask might also be a source of error, since it’s not possible to replicate the location of an uneven aluminum foil with the meniscus of the water.

Perhaps the most significant contribution to the accuracy error was in the application of the ideal gas law to this system. Ethyl acetate is a fairly large, floppy molecule having three carbons, two oxygens, and several hydrogens. It is unreasonable to assume it behaves as a point mass and even more unreasonable to believe there are no significant interactions between the ethyl acetate molecules in a vapor. The two oxygen atoms in each ethyl acetate are electronegative and contain non-bonded electrons that are sure to affect other ethyl acetate molecules for some distance.

REFERENCES