Clausius - Clapeyron Equation and Phase Transition

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1 Prelab

Phase Transitions

Prelab

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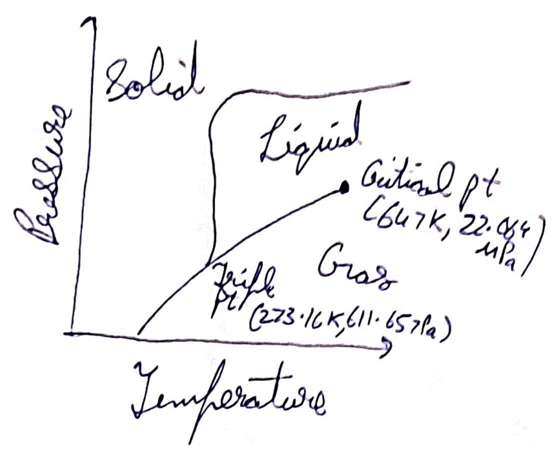
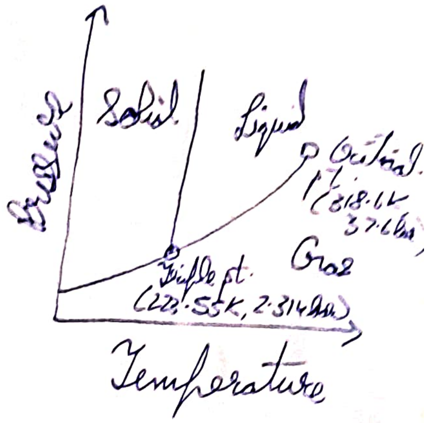
1)





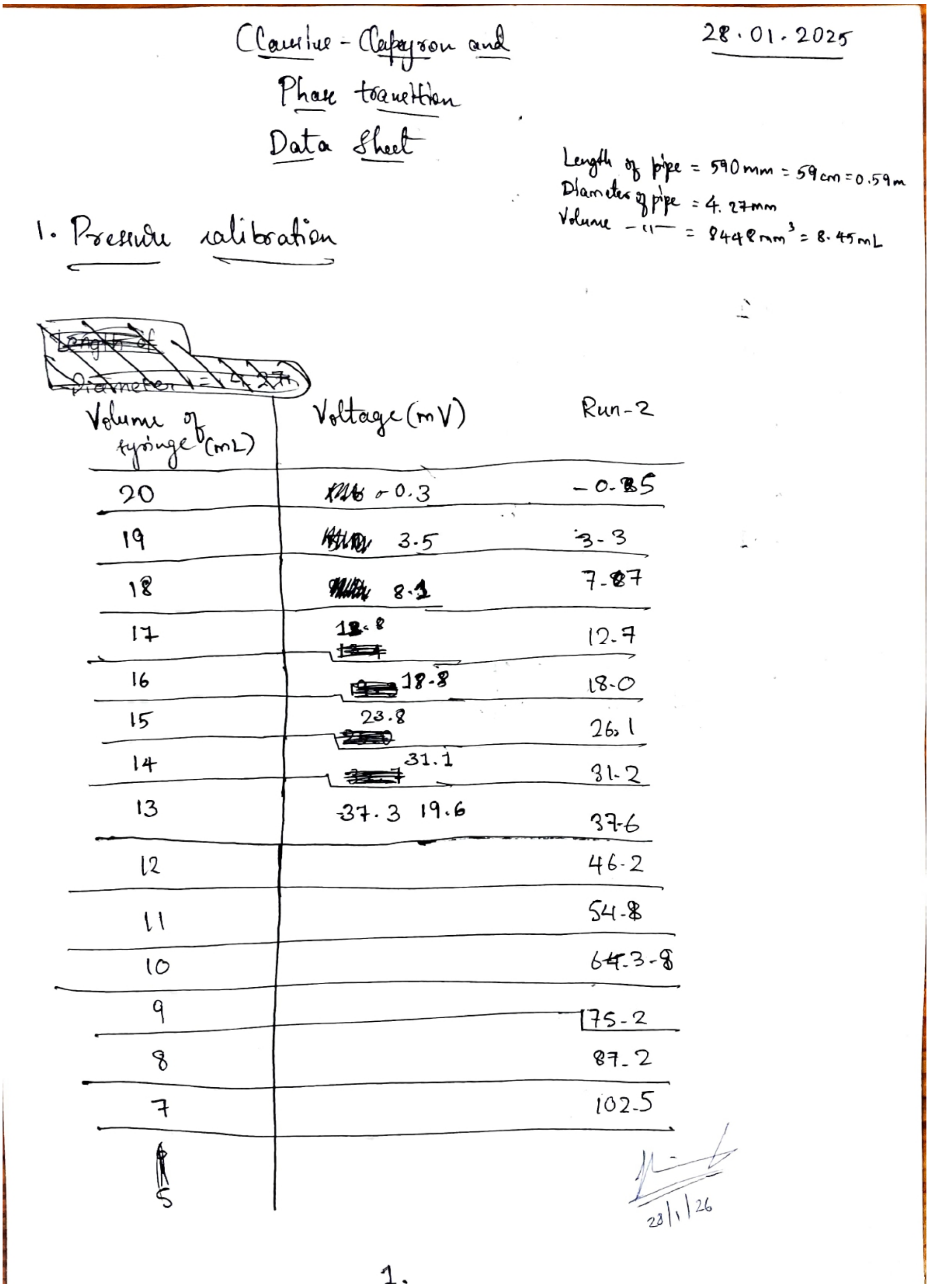
For H_2O

2) When the pressure is increased the temperature at which water boils also increases, which is evident from the phase diagram. This is because a liquid boils when its vapor pressure (which increases with temperature) equals the external pressure.

3) Due to the anomalous properties of water, the melting pt of ice decreases with ↑ pressure. This happens because ice is actually less dense than water and is thus explained via Le-Chatelier's principle.

08/01/96

2 Data



Clausius - Clapeyron and Phase transition Data Sheet

28.01.2025

Length of pipe = 590 mm = 59 cm = 0.59 m
Diameter of pipe = 4.27 mm
Volume –"– = 8448 mm^3 = 8.45 mL

1. Pressure calibration

~~Length of~~
~~Diameter = 4.27~~

Volume of syringe (mL)	Voltage (mV)	Run-2
20	-0.3	-0.85
19	3.5	3.3
18	8.1	7.87
17	12.8	12.7
16	18.8	18.0
15	23.8	26.1
14	31.1	31.2
13	37.3 19.6	37.6
12		46.2
11		54.8
10		~~64~~3.8
9		75.2
8		87.2
7		102.5
~~6~~ 5		

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1.

2. Data to verify Clausius - Clapeyron equation

Volume in container = 250 mL

Temperature (°C)	Voltage (mV)
25.1	-00.3
30.0	00.9
35.0	03.3
40.1	06.0
45.0	09.2
50.0	12.8
55.0	17.1
60.0	22.6
65.0	29.0
70.1	36.6

3. Critical point (while cooling) = 45.5 °C

(while heating) = 44.9 °C

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Table 1: Experimental Data: Total Volume, Voltage, and Calculated Pressure

Total Volume (mL)	Voltage (mV)	Pressure (atm)
28.45	−0.85	1.0000
27.45	3.30	1.0364
26.45	7.87	1.0756
25.45	12.70	1.1179
24.45	18.00	1.1636
23.45	26.10	1.2132
22.45	31.20	1.2673
21.45	37.60	1.3263
20.45	46.20	1.3912
19.45	54.80	1.4627
18.45	64.30	1.5420
17.45	75.20	1.6304
16.45	87.20	1.7295
15.45	102.50	1.8414

Table 2: Experimental Data: Temperature, Voltage, and Calculated Pressure

Temperature (°C)	Voltage (mV)	Pressure (atm)
25.1	−0.3	1.0085
30.0	0.9	1.0184
35.0	3.3	1.0381
40.1	6.0	1.0602
45.0	9.2	1.0864
50.0	12.8	1.1160
55.0	17.1	1.1512
60.0	22.6	1.1963
65.0	29.0	1.2488
70.1	36.6	1.3111

Table 3: Calculated Vapor Pressure of the Liquid at Varying Temperatures

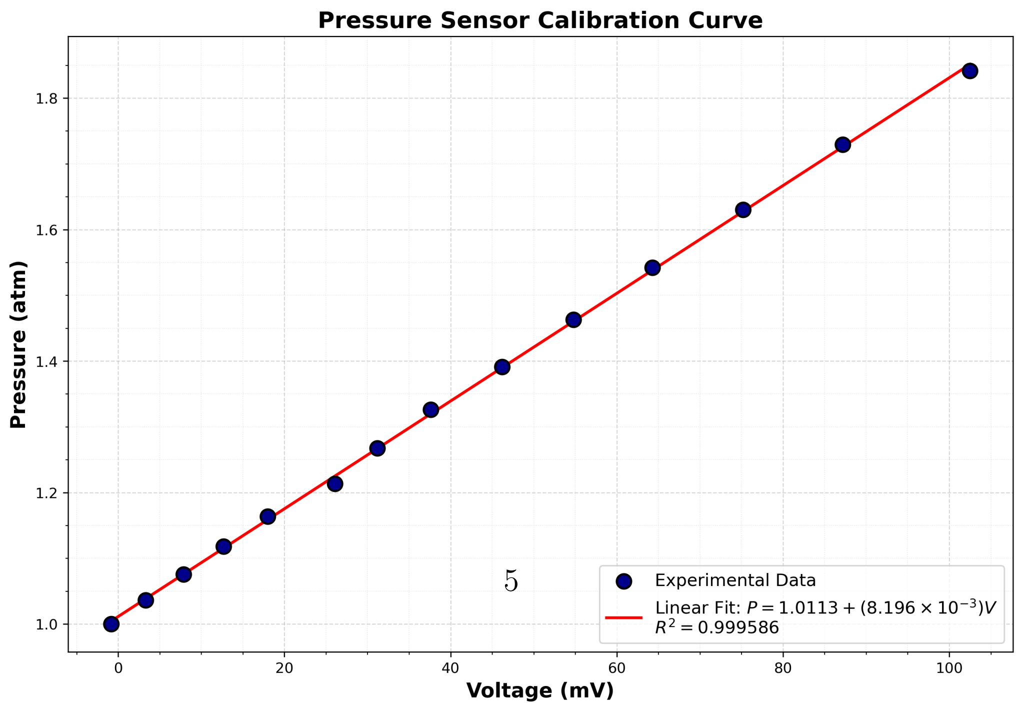
Temp (°C)	Temp (K)	Total Pressure (P_{total} / atm)	Air Pressure (P_{air} / atm)	Vapor Pressure (P_{vapor} / atm)
25.1	298.25	1.0085	0.9943	0.0142
30.0	303.15	1.0184	1.0102	0.0082
35.0	308.15	1.0381	1.0264	0.0117
40.1	313.25	1.0602	1.0429	0.0173
45.0	318.15	1.0864	1.0587	0.0277
50.0	323.15	1.1160	1.0749	0.0411
55.0	328.15	1.1512	1.0910	0.0602
60.0	333.15	1.1963	1.1071	0.0892
65.0	338.15	1.2488	1.1232	0.1256
70.1	343.25	1.3111	1.1397	0.1714

Note: P_{air} calculated using $V_{\text{air}} = 300$ mL, $V_{\text{tube}} = 8.45$ mL, and reference temperature 300 K.

Table 4: Data for Clausius-Clapeyron Plot

$1/T$ (K^{-1})	$\ln(P_{\text{vapor}})$
0.003 353	−4.2545
0.003 299	−4.8030
0.003 245	−4.4478
0.003 192	−4.0571
0.003 143	−3.5860
0.003 095	−3.1916
0.003 047	−2.8098
0.003 002	−2.4167
0.002 957	−2.0740
0.002 913	−1.7630

3 Graphs



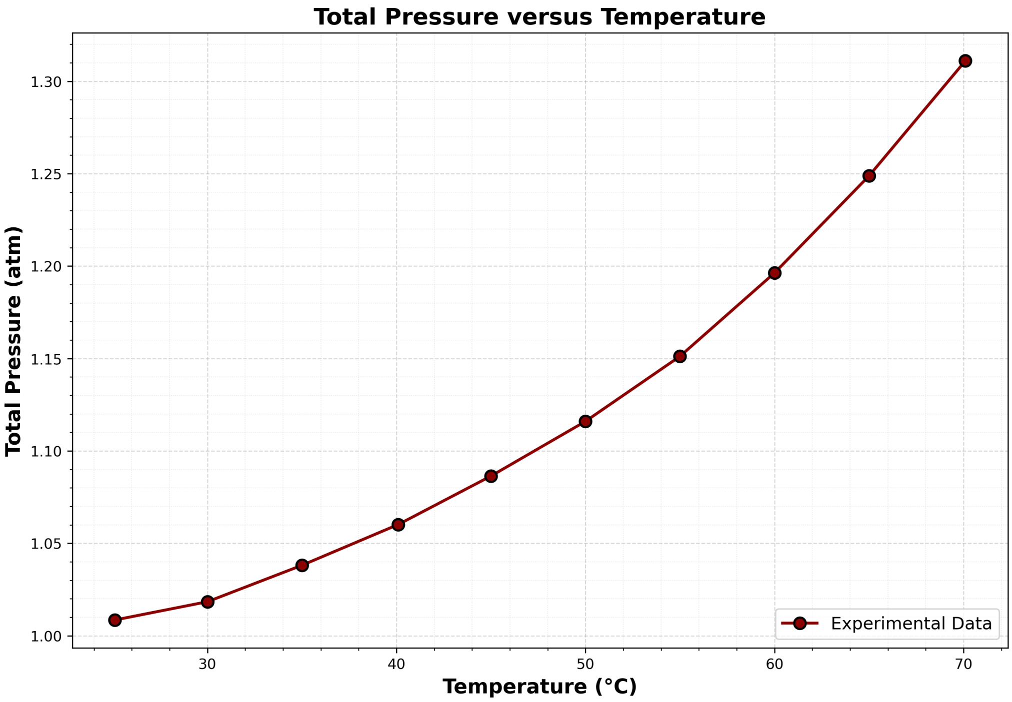


Figure 2: Total Pressure versus Temperature

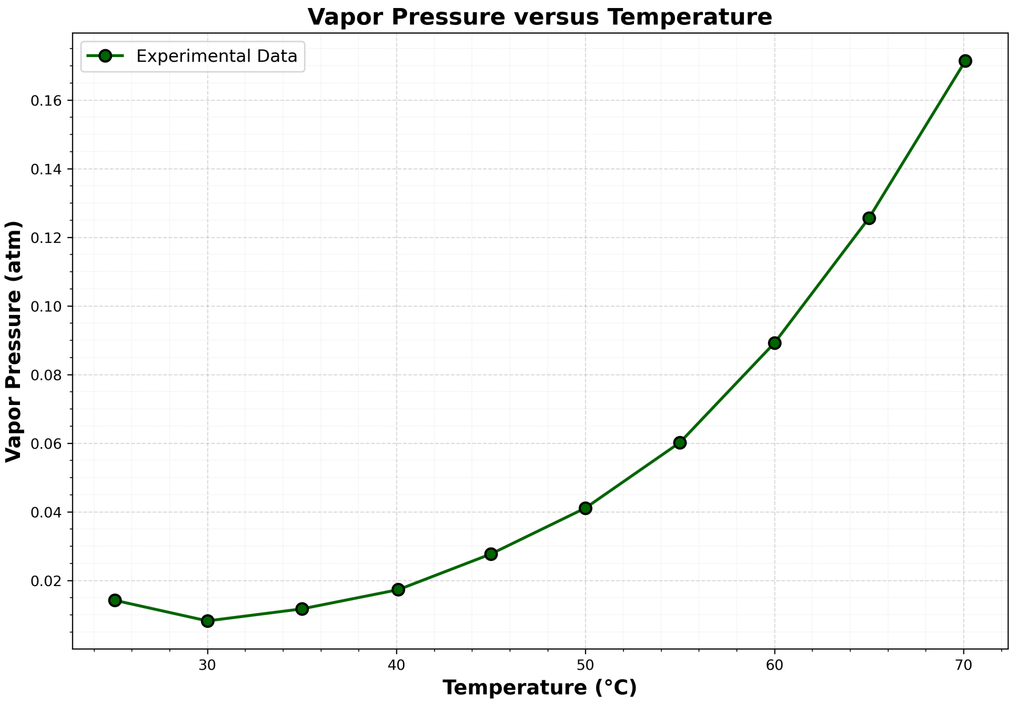


Figure 3: Vapor Pressure versus Temperature

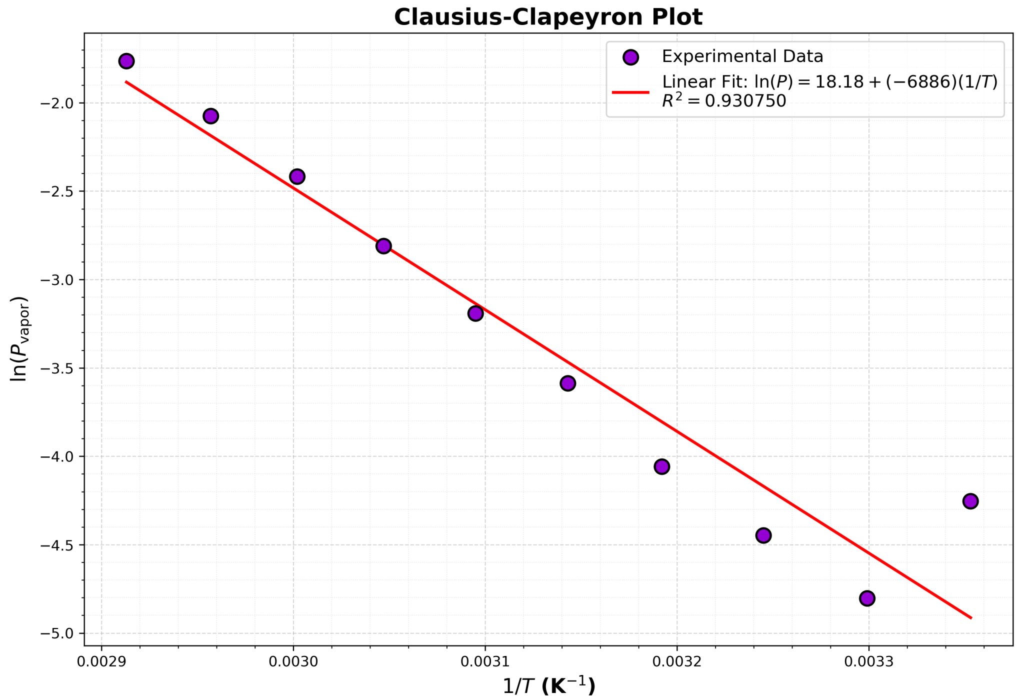


Figure 4: Clausius-Clapeyron Plot: $\ln(P_{\text{vapor}})$ versus $1/T$

4 Analysis

4.1 Pressure Sensor Calibration

A piezoelectric sensor, which generates a voltage potential when subjected to mechanical stress, was employed to measure pressure. The experiment utilized a syringe to vary the volume of air under isothermal conditions.

The syringe was initially calibrated to a volume of 20ml at atmospheric pressure, which was defined as 1atm. During the procedure, the air volume within the tube of the syringe was measured to be 8.45ml.

For isothermal processes, the system follows Boyle's Law with reference state $V_0 = 28.45$ ml at $P_0 = 1$ atm:

$$P = \frac{P_0 V_0}{V_{\text{total}}}$$

Linear regression of the pressure-voltage data (Figure 1) yields the calibration equation:

$$P = (1.011 \pm 0.002) + (8.20 \pm 0.05) \times 10^{-3} V \quad (R^2 = 0.9996)$$

where P is in atm and V is in mV.

4.2 Total Pressure vs Temperature

Using the calibration equation, the total pressure was calculated for each voltage reading. The resulting pressure values are presented in Table 2 and plotted against the corresponding temperatures in Figure 2.

4.3 Vapour Pressure vs Temperature

To get the vapour pressure, we use Dalton's law of partial pressures:

$$P_{\text{total}} = P_{\text{air}} + P_{\text{vapor}}$$

The air pressure is given by:

$$P_{\text{air}} = P_0 \frac{\frac{V_{\text{air}}}{300} + \frac{V_{\text{tube}}}{300}}{\frac{V_{\text{air}}}{T} + \frac{V_{\text{tube}}}{300}}$$

This equation holds as only the air inside the container is heated, not the air in the tube. Here, $V_{\text{air}} = 550ml - 250ml = 300ml; V_{\text{tube}} = 8.45ml$; $P_0 = 1atm$; T is the temperature in Kelvin.

The vapour pressure is then calculated and tabulated against temperature in Table 3. It is then plotted in Figure 3.

4.4 Clausius - Clapeyron Equation

The Clausius-Clapeyron equation states:

$$\frac{dP}{dT} = \frac{\Delta H}{T\Delta V}$$

where H is the molar latent heat of vaporization and ΔV is the volume change upon vaporization approximated as V_{gas}.
Using the ideal gas law $PV_{\text{gas}} = nRT$, the equation simplifies to:

$$\frac{dP}{dT} = \frac{HP}{nRT^2}$$

Integrating from (P_1, T_1) to (P_2, T_2):

$$\ln\left(\frac{P_2}{P_1}\right) = \frac{\Delta H}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

Rearranging with $P_1 = P_0$ and $T_1 = T_0$:

$$\ln P = -\frac{\Delta H}{RT} + \left(\frac{\Delta H}{RT_0} + \ln P_0\right)$$

So, the log of Vapor pressure and 1/Temperature data is tabulated in Table 4 and plotted in Figure 4. Linear regression yields:

$$\ln(P_{\text{vapor}}) = (18.18 \pm 2.08) + (-6886 \pm 664)\frac{1}{T} \quad (R^2 = 0.931)$$

From the slope $m = -\frac{\Delta H_{\text{vap}}}{R}$, with $R = 8.314$ J/(mol·K):

$$\Delta H_{\text{vap}} = -mR = 57,251 \text{ J/mol}, \quad \delta(\Delta H_{\text{vap}}) = R \times \delta m = 5,520 \text{ J/mol}$$

$$\boxed{\Delta H_{\text{vap}} = 57.3 \pm 5.5 \text{ kJ/mol}} \tag{1}$$

5 Uncertainty Analysis

All the required uncertainties have been calculated and propagated according to the standard rules of error propagation. These have been included in the analysis above. The literature value of ΔH_{vap} for water is 40.65 kJ/mol. So, the percentage error in our experimental value is:

$$\text{Percentage Error} = \left|\frac{57.3 - 40.65}{40.65}\right| \times 100\% = 41.0\%$$

6 Critical Point of SF_6

The phase transition temperature for SF6 was recorded as:

- Heating: 44.9 °C
- Cooling: 45.5 °C
- Average: 45.2 °C

7 Conclusion

This experiment successfully investigated phase transitions and vapor pressure behavior:

- Piezoelectric pressure sensor calibration: $P = (1.011 \pm 0.002) + (8.20 \pm 0.05) \times 10^{-3} V$ atm ($R^2 = 0.9996$)
- Total pressure increased from 1.01 to 1.31 atm over temperature range 25-70°C
- Vapor pressure calculated using Dalton's law ranged from 0.008 to 0.171 atm
- Latent heat of vaporization from Clausius-Clapeyron analysis: $\Delta H_{\text{vap}} = 57.3 \pm 5.5$ kJ/mol
- SF critical point temperature: 45.2°C (average of heating and cooling cycles)
- Percentage error compared to water's literature value (40.65 kJ/mol): 41.0%