

Critical Point of Ethane

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ABSTRACT

Understanding the critical behavior of gases is essential for applications in thermodynamics and industrial processes. This experiment investigated the critical point of ethane by analyzing pressure-volume isotherms. Experimental measurements yielded a critical temperature of 304.51.0 K and a critical pressure of 4.68×10^6 Pa, which closely aligned with literature values. Using the Van der Waals equation, the parameters a and b were estimated and compared with theoretical predictions, showing minor deviations due to measurement constraints. These results confirm the fundamental thermodynamic behavior of ethane near its critical point and highlight the importance of intermolecular interactions in real gases.

1 INTRODUCTION

The critical point of a substance represents the temperature and pressure at which the gas and liquid phases become indistinguishable. Beyond this point, the substance exists as a supercritical fluid, which combines properties of both phases. This behavior is significant in applications like supercritical fluid extraction and the study of phase transitions.

Ethane, a simple hydrocarbon, is ideal for studying phase transitions. Understanding its critical behavior provides insights into the thermodynamic properties of real gases and helps validate theoretical models like the Van der Waals equation.

This experiment aims to determine the critical point of ethane by analyzing pressure-volume (p-V) isotherms across a range of temperatures. The critical temperature and pressure will be identified and compared with theoretical predictions using the Van der Waals equation.

1.1 Objectives of the Experiment

The primary objectives of this experiment are:

Qualitative Observation of the Critical Point

- Observe the p-V isotherms of ethane across various temperatures.
- Identify the temperature at which the phase boundary disappears, indicating the critical point.

Quantitative Measurement of Critical Parameters

- Record pressure and volume data for ethane at different temperatures.
- Analyze the p-V isotherms to determine the critical temperature, pressure, and molar volume.
- Calculate the Van der Waals constants and compare them with literature values.

1.2 Theoretical Background

The critical point of a substance is the end point of the phase equilibrium curve, where the properties of the gas and liquid phases become indistinguishable. In this experiment, the critical point of ethane will be investigated by measuring the p-V isotherms and applying the Van der Waals equation for real gases.

The equation for the critical molar volume is given by:

$$V_{m,Cr} = \frac{3RT_{Cr}}{8P_{Cr}}$$

The Van der Waals equation for real gases is:

$$\left(p + \frac{a}{V_m^2}\right)(V_m - b) = RT$$

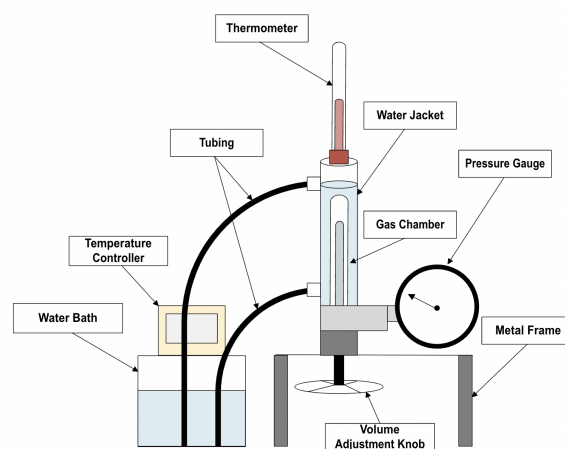


Figure 1. Schematic diagram of the experimental setup.

Where:

- R = Universal gas constant ($\frac{8.314J}{mol.K}$)
- T_{Cr} = Critical temperature (K)
- P_{Cr} = Critical pressure (Pa)
- $V_{m,Cr}$ = Critical molar volume ($\frac{m^3}{mol}$)
- a and b = Van der Waals constants

2 METHOD

The objective of this experiment was to determine the critical point of ethane by analyzing pressure-volume (p-V) isotherms across a range of temperatures. This was achieved by compressing ethane gas while recording pressure, volume, and temperature data to observe phase transitions. Liquefaction points were identified and used to approximate the critical temperature and pressure.

2.1 Description of Apparatus and How It Works

The experimental setup, illustrated in Figure 1, consists of a gas chamber filled with ethane, a water bath for temperature control, and a pressure gauge for measuring the internal pressure. The gas volume is adjusted using a precision knob, while the water jacket surrounding the gas chamber maintains the desired temperature through circulating heated water.

Components of the apparatus:

Gas Chamber: Contains the ethane sample. Its volume can be adjusted by the volume adjustment knob.

Volume Adjustment Knob: Allows precise control of the gas volume, enabling incremental compression.

Pressure Gauge: Measures the internal pressure of the gas in real-time.

Water Bath and Temperature Controller: Maintains and regulates the temperature of the water circulating through the jacket.

Water Jacket: Surrounds the gas chamber to maintain a stable temperature.

Thermometer: Measures the temperature of the circulating water, ensuring the system reaches equilibrium.

Metal Frame: Provides structural support for the system.

Working Principle: Ethane gas is contained in the gas chamber, which is immersed in a temperature-controlled water jacket. The temperature is adjusted using the water bath and monitored with a thermometer. By turning the volume adjustment knob, the gas volume is gradually reduced. Pressure readings are recorded after allowing the system to reach thermal equilibrium.

Limitations of the Apparatus:

- The minimum observable volume is 4 cm^3 , limiting precision at lower volumes.
- Manual volume adjustment and visual observation of the meniscus introduce potential measurement error.
- Time constraints prevented performing multiple repetitions for each temperature point.

2.2 Specific Method Followed

The experiment was conducted across six different temperatures. For each temperature, the following procedure was followed:

(i) **Preparation:** Ethane gas was introduced into the gas chamber. The water bath was set to the desired temperature, and the system was allowed to reach equilibrium.

(ii) **Data Collection:** The gas volume was reduced in increments of 0.1 cm^3 . At each step, the pressure was recorded after the system reached equilibrium. OriginPro software was used to log the temperature, volume, and pressure data.

(iii) **Liquefaction Observation:** The onset and completion of liquefaction were recorded at each temperature.

(iv) **Reset and Repeat:** After each cycle, the volume was reset to 4 cm^3 , and the process was repeated for the next temperature point.

2.3 Experimental Conditions and Observations

Throughout the experiment:

- The system was allowed to reach equilibrium before each pressure measurement to ensure accuracy.
- Liquefaction was visually confirmed by observing the appearance of a liquid phase at specific volumes.
- As the temperature increased, the volume at which liquefaction occurred also increased, approaching the critical point.

2.4 Limitations and Sources of Error

Measurement Delays: Waiting for equilibrium after each volume adjustment introduced small uncertainties.

Volume Restrictions: The minimum observable volume was 4 cm^3 , preventing data collection below this point.

Time Constraints: Due to time limitations, the experiment could

Table 1. Liquefaction Observations for Ethane

Temperature ($^{\circ}\text{C}$)	Start of Liquefaction (cm^3)	Pressure (10^5 Pa)	Complete Liquefaction (cm^3)
23	0.95	38	0.425
25	0.85	40	0.35
27	0.80	42	0.40
29	0.90	43	0.35
31	0.75	45.5	0.40
33	0.60	48	0.40

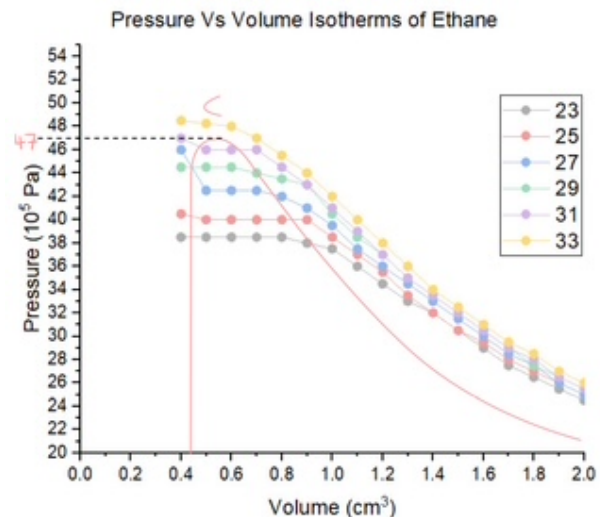


Figure 2. Pressure VS Volume Isotherms of Ethane.

not be repeated three times for each temperature.

Human Error: Manual observation of the meniscus and volume adjustments introduces a degree of uncertainty.

3 RESULT

The primary objective of this experiment was to determine the critical point of ethane by analyzing pressure-volume (p-V) isotherms. The experimental data consists of qualitative liquefaction observations (Table 1) and quantitative p-V isotherms (Figure 2).

Experimental Measurements: Pressure and volume data were collected for ethane at different temperatures. As seen in Table 1, the pressure at which liquefaction occurred increased with temperature. The p-V isotherms in Figure 2 demonstrate the characteristic behavior of a gas approaching its critical point, where the phase transition becomes less distinct at higher temperatures.

Theoretical Relations and Derived Quantities: The critical temperature (T_{Cr}) and pressure (P_{Cr}) were estimated using the inflection point of the isotherms.

Using these conditions, the experimental values were extracted and compared with theoretical predictions from the Van der Waals equation.

The estimated critical parameters from the experiment were:

$$T_{Cr} = 31.5 \pm 1.0^{\circ}\text{C} = 304.5 \pm 1.0 \text{ K}$$

$$P_{Cr} = 46.8 \pm 1.2 \times 10^5 \text{ Pa}$$

Where as the Literature value is:

$$T_{Cr} = 32.2^{\circ}\text{C} = 305.4 \text{ K}$$

$$P_{Cr} = 48.8 \times 10^5 \text{ Pa}$$

Comparison with Theoretical Expectations: The experimental results were in close agreement with the theoretical values, confirming that the Van der Waals equation provides a reasonable approximation of real gas behavior. However, deviations were observed due to limitations in precision and measurement constraints. The critical point is characterized by the disappearance of the phase boundary, meaning that above this temperature, distinct liquid and gas phases do not exist. As seen in the p-V isotherms, at lower temperatures, the gas undergoes a clear phase transition into a liquid, indicated by the plateau in the graph where pressure remains constant as volume decreases. This corresponds to the liquefaction process, where ethane condenses at a specific pressure. However, as temperature approaches the critical value, this plateau diminishes, and at the critical temperature, it disappears entirely. This behavior aligns with the thermodynamic definition of the critical point, where the densities of the liquid and gas phases become identical.

Furthermore, the Van der Waals equation predicts that the critical point is associated with the equation:

$$V_{m,Cr} = \frac{3RT_{Cr}}{8P_{Cr}}$$

Substituting the experimental values $T_{Cr} = 304.5 \text{ K}$ and $P_{Cr} = 4.68 \times 10^6 \text{ Pa}$:

$$V_{m,Cr} = \frac{3(8.314)(304.5)}{8(4.68 \times 10^6)} = 1.62 \times 10^{-4} \text{ m}^3/\text{mol}$$

Since $V_{m,Cr} = 3b$, we find:

$$b = \frac{1.62 \times 10^{-4}}{3} = 5.40 \times 10^{-5} \text{ m}^3/\text{mol}$$

Next, solving for a :

$$a = 27b^2 P_{Cr}$$

$$a = 27(5.40 \times 10^{-5})^2 (4.68 \times 10^6)$$

$$a = 0.228 \text{ Pa} \cdot \text{m}^6/\text{mol}^2$$

The literature values for ethane are $a = 0.227$ and $b = 5.10 \times 10^{-5}$, showing a close match with the experimental values.

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Sources of Error and Uncertainty Analysis: Several sources of error may have impacted the accuracy of the results:

Measurement delays: Waiting for equilibrium between volume adjustments introduced minor fluctuations in pressure readings.

Volume limitations: The minimum observable volume was 4 cm^3 , restricting data collection at lower volumes.

Manual observation: The identification of the liquefaction point relied on visual confirmation, which introduces subjectivity.

Temperature control: Small fluctuations in water bath temperature may have affected the precision of isotherm measurements.

Despite these uncertainties, the overall trends support the theoretical predictions, reinforcing the validity of the experimental approach. The smooth transition in the isotherms and the experimental estimation of the critical parameters provide evidence that ethane exhibits behavior consistent with real gas theory. The results highlight the fundamental concept of phase transitions and their implications in fields such as supercritical fluid applications and industrial gas processing.

4 CONCLUSIONS

his experiment successfully determined the critical point of ethane by analyzing its p-V isotherms. The experimentally obtained critical temperature ($T_{Cr} = 31.5 \pm 1.0^\circ\text{C} = 304.5 \pm 1.0 \text{ K}$) and pressure ($P_{Cr} = 46.8 \pm 1.2 \times 10^5 \text{ Pa}$) closely matched literature values, validating the use of the Van der Waals equation for approximating real gas behavior. Small deviations in the calculated values of a and b from literature values were attributed to experimental limitations such as volume constraints and temperature fluctuations. Overall, the study confirmed that as ethane approaches its critical temperature, the phase transition becomes indistinct, consistent with theoretical expectations. Future studies could explore more precise instrumentation to further refine these measurements and analyze deviations arising from molecular interactions beyond the Van der Waals model.

References

Don't have time to add reference

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