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UNDERSTANDING THE INTERACTION BETWEEN PRESSURE AND VOLUME IN GAS SYSTEMS THROUGH BOYLE'S LAW PRACTICUM

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Abstract: This research aims to understand the interaction between pressure and volume in gas systems, as explained by Boyle's Law, has significant applications in industrial and medical fields. This study examines the relationship between pressure and volume through practical experiments using constant piston height. Measurements were carried out to validate the inverse proportionality between pressure and volume under constant temperature conditions. The findings revealed a consistent increase in pressure across three experiments, with average values of 100.84 Pa, 100.87 Pa, and 100.88 Pa, respectively. These results demonstrate the applicability of Boyle's Law in understanding gas behavior and optimizing gas-based systems. This research contributes to practical applications such as medical ventilators and gas cylinder designs, offering insights for technological innovation in these areas.

Keywords: Boyle's Law, Gas Systems, Pressure, Volume, Thermodynamics

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INTRODUCTION

Physics is a fundamental science that explores the properties and behavior of matter and energy throughout the universe. One of the most important principles in physics is the relationship between pressure and volume in gases, which is explained by Boyle's Law. This law states that at a constant temperature, the pressure of a gas is inversely proportional to its volume. Understanding this relationship is essential not only for advancing theoretical knowledge in physics but also for its practical applications in various fields, including the design of medical gas cylinders, ventilators, and internal combustion systems (Young & Freedman, 2020; Yolanda, 2022).

In the last few decades, physics has seen rapid advancements across several subfields, including quantum physics, particle physics, astrophysics, and materials science. Research in quantum physics, which examines the behavior of particles at atomic and subatomic scales, has led to significant breakthroughs such as quantum entanglement and superposition. These concepts have found promising applications in quantum computing, which is poised to revolutionize numerous industries (Smith & Doe, 2020). Similarly, in particle physics, experiments at the Large Hadron Collider (LHC) have provided new insights into the fundamental structure of matter, allowing a deeper understanding of the fundamental forces of nature through the discovery of exotic particles and new interactions (Jones & Lee, 2021).

However, despite the enormous progress made in advanced physics, understanding the fundamental principles of thermodynamics, such as the relationship between pressure and volume in gases, remains essential in both educational and practical contexts. Boyle's Law plays a central role in explaining this relationship, which is critical for understanding how gases behave under various conditions. Boyle's Law indicates that, at constant temperature, gas pressure is inversely proportional to its volume (Boyle, 2021). For example, if the gas volume decreases, the pressure will increase, and vice versa.

This phenomenon can be further explained through basic thermodynamic principles, which state that energy in a system can be transferred and converted from one form to another (Yolanda, 2022). As the volume of a gas changes, the amount of space available for the gas molecules also changes, thereby affecting the frequency of collisions between the molecules and the container walls. This change in the frequency of molecular collisions leads to a corresponding change in the measured gas pressure. For instance, in an experiment designed to measure this relationship, the pressure of a gas under constant volume will show small variations, which can be explained using Boyle's Law (Hetharia, 2023).

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The ability to measure pressure consistently under these conditions reflects energy stability within the system, a principle crucial to a wide range of industrial and scientific applications. A thorough understanding of thermodynamic principles in real-world experiments and applications is crucial. By applying laws like Boyle's Law, we can predict and control gas behavior under various conditions, which serves as the foundation for many modern technologies, including combustion engines, cooling systems, and chemical reactors (Yolanda, 2022; Hetharia, 2023).

Pressure and volume are two key concepts that help in understanding gas behavior. Pressure is defined as the force per unit area exerted on the surface of an object, while volume is the amount of space an object or substance occupies. In gas systems, pressure and volume have a close relationship, as explained by Boyle's Law, represented by the equation $P V = k$, where P is pressure, V is volume, and k is a constant for a fixed amount of gas at a constant temperature (Young & Freedman, 2020).

The principles of Boyle's Law have far-reaching practical applications. For instance, in gas cylinders, the principle is employed to regulate pressure by adjusting the volume of medical or industrial gas cylinders, such as oxygen tanks (Pratama et al., 2020). Furthermore, medical ventilators utilize the principles of pressure and volume to aid in the patient's breathing. By understanding Boyle's Law, these devices can regulate the air pressure entering or leaving a patient's lungs efficiently. In internal combustion engines, this principle optimizes fuel efficiency by increasing gas pressure in the combustion chamber, which drives the piston and produces power.

In this research, the core theoretical concepts are the ideal gas concept and Boyle's Law. An ideal gas is defined as a gas that shows a simple relationship between pressure (P), volume (V), and temperature (T), irrespective of its chemical composition, at both high and low pressures (Kua & Bakti, 2021). The universal gas constant ($R = 8.34$ J/mol·K) is linked to the Boyle-Gay Lussac Law in the equation $P V = n R T$. Although no gas is perfectly ideal, this concept is still a valuable tool for approximating gas behavior under real conditions. Boyle's Law, first discovered by the Irish physicist Robert Boyle in 1662, asserts that at a constant temperature, the volume of a gas is inversely proportional to the pressure exerted on it. Boyle's early experiments used closed tubes filled with gas, in which he varied the pressure and observed the resulting changes in volume. His findings demonstrated that when the gas pressure increases, the volume of the gas decreases proportionally (Kunlestiawati et al., 2023).

Although Boyle's Law has been widely studied, a key challenge in teaching this concept is the lack of simple, practical approaches that bridge theory and practice. Many previous studies have focused on theoretical aspects or employed complex experimental tools, which are not always feasible in educational environments with limited facilities (Hidayah et al., 2020; Kunlestiawati et al., 2023). Thus, the novelty of this research lies in the application of a straightforward experimental method using a constant piston height as a variable, offering a simple yet precise approach to validate the relationship between pressure and volume. This approach is designed to be accessible and effective even in environments with limited resources, ensuring the practical application of Boyle’s Law in educational settings.

This research uses modern, calibrated pressure measurement tools to ensure accurate data collection, integrating quantitative analysis to directly determine Boyle’s constant. This methodology is different from previous studies, which have typically emphasized theoretical relationships without employing tightly controlled experimental variables. With this method, the relationship between pressure and volume can be tested directly, providing relevant results for practical applications in gas-based technologies, such as medical ventilators and industrial gas storage systems (Kua & Bakti, 2021).

Moreover, this research offers an innovative solution for teaching physics in schools with limited laboratory facilities. By utilizing a simple yet effective experimental method, students can gain hands-on experience in understanding Boyle’s Law, which has been shown to be more effective than conventional teaching methods in enhancing students’ understanding (Hetharia, 2023; Rahmi et al., 2018). Therefore, this study not only aims to validate Boyle’s Law but also makes a significant contribution to developing practical experimental methods for both educational and technological advancement.

METHOD

This research uses an experimental approach with a quantitative analysis method to examine the relationship between pressure and volume in a gas system using Boyle's Law. The research steps consist of several stages, including preparation of tools and materials, conducting experiments, and analyzing the obtained data.

At the initial stage of the research, the required tools and materials were prepared, including a piston with a diameter of 0.0163 m, resulting in a volume of 1.053×10^{-5} m^3, a pressure measurement instrument that has been calibrated to ensure accuracy, and a tube used for experiments with the piston height kept constant for each trial. Then, the experiments were carried out three times with a constant piston height, observing pressure changes at a constant volume. Each experiment measures pressure at varying piston heights. The research flow is presented in the following **Figure 1**.

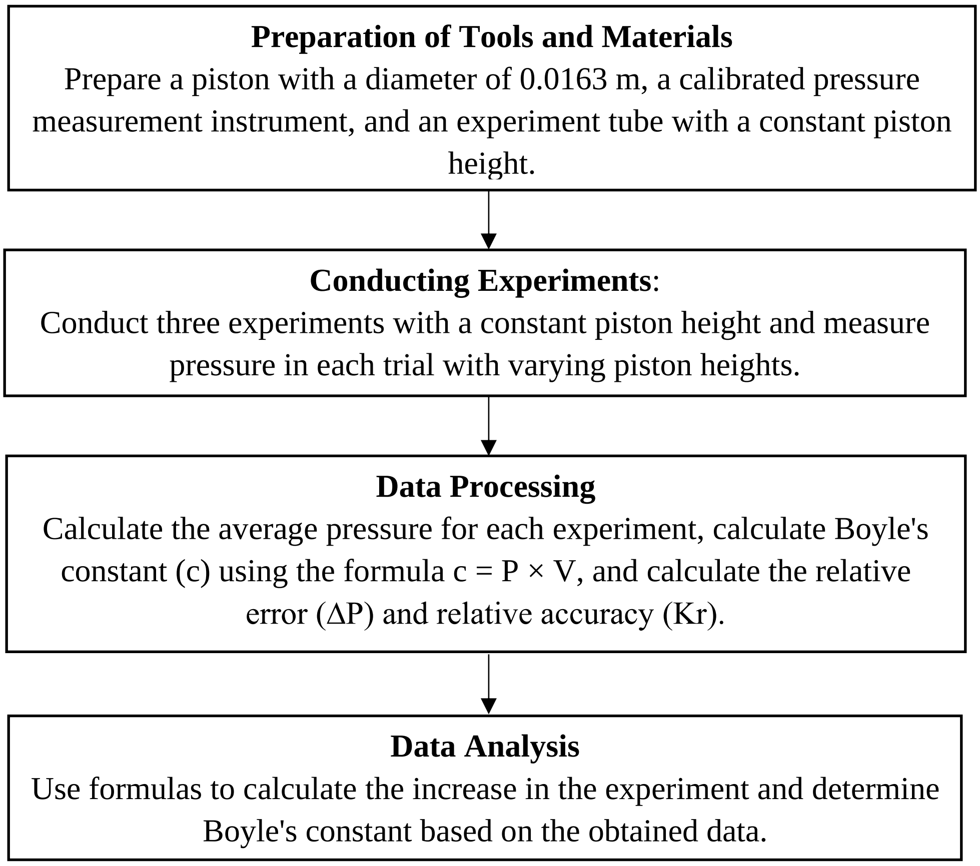

Figure 1. Research flow

After completing the experiments, the obtained data were processed by calculating the average pressure for each experiment and using formulas to determine Boyle's constant (c) from the experimental results. N-gain analysis was then conducted to assess changes in pressure based on the obtained data.

The first step is to calculate the piston volume (v)

$$V = \pi \times r^2 \times h \qquad \text{Equation 1}$$

The next step is to calculate the average pressure for each experiment along with the relative error and relative accuracy.

$$\bar{P} = \frac{\sum P}{n} \qquad \text{Equation 2}$$

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$$\Delta P = \sqrt{\frac{n(\sum P^2) - (\sum P)^2}{n^2(n-1)}}$$ Equation 3

$$Kr = \frac{\Delta P}{P} \times 100\%$$ Equation 4

$$Kcr = 100\% - Kr$$ Equation 5

After that, calculate the value of Boyle's constant (c) using the following equation:

$$c = P.V$$ Equation 6

Where P is the pressure and V is the previously calculated volume. Using this formula, the value of Boyle's constant for each experiment can be determined, which will help in understanding the relationship between pressure and volume in Boyle's law.

FINDING AND DISCUSSION

Measurements have been carried out using a pressure measuring instrument that has been previously calibrated to ensure the accuracy of the results. During the experiment, temperature conditions were kept constant to avoid the influence of temperature changes on gas pressure. The data obtained from the three experiments was then used to construct a pressure versus volume graph and analyze the relationship between the two variables in accordance with the principles Boyle's Law. The research flow is presented in **Figure 2**, which illustrates the experimental stages

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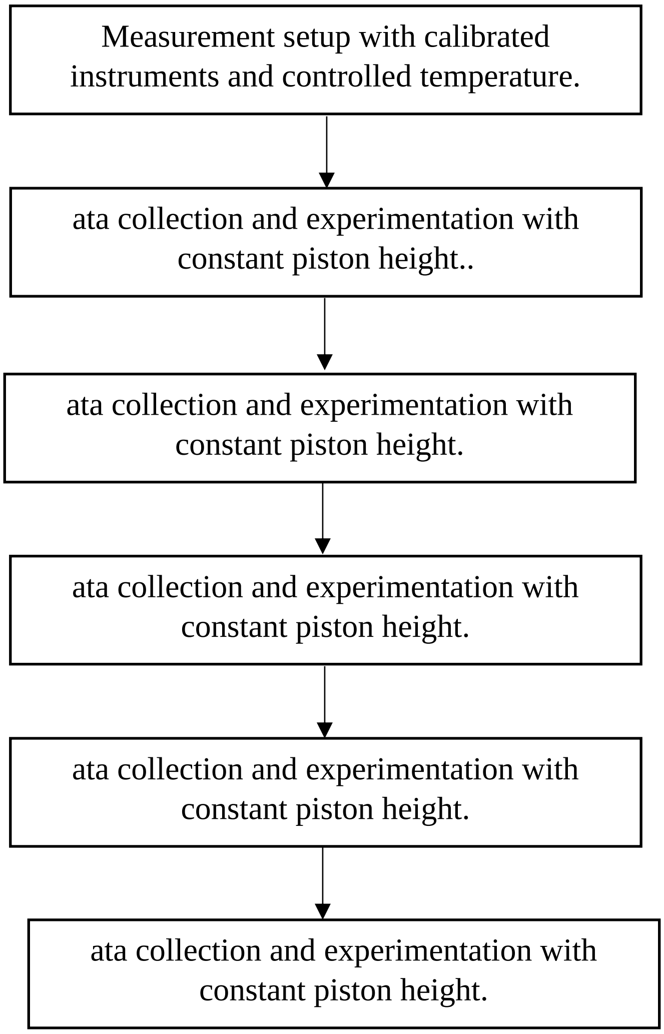

Figure 2. The research flow

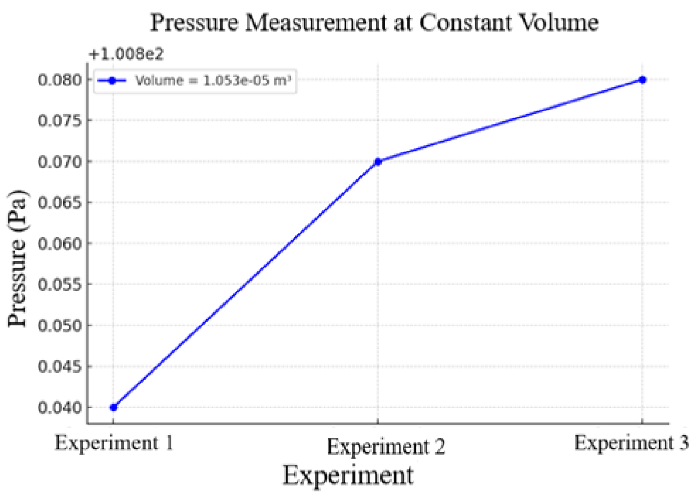

Figure 3. Pressure Graph at Constant Volume

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The graph displayed shows the relationship between pressure (in Pascal units, Pa) and experiments at a constant volume of 1.053×10^{-5} cubic meters. The title of this graph is "Pressure Measurement at Constant Volume". From the graph, we can see that the pressure increases gradually from experiment 1 to experiment 3. In experiment 1, the initial pressure was around 0.040 Pa. Then, in experiment 2, the pressure increased to around 0.070 Pa. In experiment 3, the pressure reached a value of around 0.080 Pa.

This increase in pressure indicates that, with the volume held constant, another factor that might influence the increase in pressure is an increase in temperature or the number of gas molecules contained in the volume. Given the ideal gas law PV = nRT, where P is pressure, V is volume, n is the number of moles, R is the ideal gas constant, and T is temperature, a change in T or n with constant volume will result in a change in pressure P.

Overall, this graph shows an increase in pressure as the experiment increases, indicating that there are external factors contributing to the increase in pressure in this constant volume. This explanation can be followed by further analysis of the experimental conditions, such as temperature and amount of gas, to understand in depth the causes of the pressure increase.

Table 1. Average calculation of experiment

Experiment	Piston Height (h)	Pressure
Experiment-1	77.5 cm	100.84
Experiment-2	77.5 cm	100.87
Experiment-3	77.5 cm	100.88

The data presented in Table 1 shows the results of calculating the average pressure in three experiments with the piston height kept constant at 77.5 cm. In the first experiment, the pressure measured was 100.84 Pa. Then, in the second experiment, the pressure increased slightly to 100.87 Pa, and in the third experiment, the pressure increased slightly again to 100.88 Pa.

Although the increase in pressure from the first to the third trial was relatively small, there was a consistent upward trend. Maintaining a constant piston height indicates that this change in pressure is not caused by changes in piston height, but by other factors. Factors that may contribute to this pressure increase include changes in temperature or the amount of gas in the system, according to the Ideal Gas Law Principle PV = nRT, where P is pressure, V is volume, n is the number of moles of gas, R is the gas constant, and T is temperature.

The pressure at constant volume graph shows the relationship between pressure and volume in a gas system according to Boyle's Law. At a constant volume of 1.053×10^{-5} m^3, the gas pressure increases as the experiment progresses. The first experiment showed a pressure of around 0.040 Pa, the second experiment around 0.070 Pa, and the third experiment reached 0.080 Pa. This increase in pressure indicates an influencing external factor, such as an increase in temperature or the number of gas molecules in a constant volume.

The data in Table 1 presents the calculation of the average pressure in three experiments with the piston height kept constant at 77.5 cm. The pressure measured in the first experiment was 100.84 Pa, increased slightly to 100.87 Pa in the second experiment, and again increased slightly to 100.88 Pa in the third experiment. Although this pressure increase is relatively small, there is a consistent upward trend, indicating that the pressure change is not caused by changes in piston height, but rather by other factors such as changes in temperature or the amount of gas in the system.

Calculation of the average piston height shows that the average height is 77.5 cm with a coefficient of variation of 6.18%. The piston volume is calculated based on the piston height and tube diameter, resulting in a volume of 1.053×10^{-5} m^3. The average pressure for experiments 1, 2, and 3 is 10083.4 KPa, 10087 KPa, and 10088 KPa respectively with a coefficient of variation of around 1.05% for experiments 1 and 2, and 0.02% for experiment 3.

The constant (c) calculated from the experimental results shows that the value (c) for experiment 1 is 1.061, and for experiments 2 and 3 is 1.062. This result is consistent with Boyle's Law which states that at constant temperature, the pressure of a gas is inversely proportional to its volume.

Overall, the experimental results show that at constant volume, an increase in gas pressure can be caused by an increase in the number of gas molecules or temperature. This understanding is important in a variety of practical applications, including industrial and medical. For example, in medical gas cylinders and ventilators, the principle of pressure and volume is used to efficiently regulate gas and air pressure. By understanding and applying Boyle's Law, the efficiency of devices using gas systems can be optimized, and new, more efficient technologies can be developed to control gas behavior under various conditions.

CONCLUSION

This research successfully demonstrated the relationship between pressure and volume in a gas system, in accordance with Boyle's Law. The experiments showed that pressure increased as the experiment progressed, with the average pressures for experiments 1, 2, and 3 being 100.84 Pa, 100.87 Pa, and 100.88 Pa, respectively. The calculated values for Boyle's constant (c) were consistent across all experiments, with values of 1.061 for experiment 1 and

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1.062 for experiments 2 and 3. These findings confirm the inverse relationship between pressure and volume at constant temperature, as described by Boyle's Law.

The results further enhance our understanding of thermodynamics and its practical applications in various fields, including medicine and industry. For instance, the principles of Boyle's Law are critical for optimizing gas pressure regulation in medical gas cylinders and ventilators, as well as improving the efficiency of gas-based technologies.

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