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Use of Boyle's Law Apparatus in Boyle's Law Practicum: A Cookbook Model Approach to Apparatus Testing and School Implementation

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Abstract: This study aims to evaluate the effectiveness of Boyle's Law Apparatus in teaching the relationship between pressure and volume of gas at constant temperature, utilizing a structured cookbook practicum approach. An experimental method was employed at MA Alinayah Bandung, involving four variations of pressure and ten trials for each variation, resulting in a total of 40 trials. The tools used included vacuum tubes, vacuum pumps, manometers, and volume meters for accurate measurement of pressure and volume. Results demonstrated a consistent inverse relationship between gas volume and pressure, aligning with Boyle's Law, where P × V remained constant. The structured approach facilitated accurate data collection and enhanced students' comprehension of gas behavior principles. The findings highlight the importance of practical experimentation in physics education, providing students with hands-on experience and fostering critical thinking skills for a more interactive learning environment.

Keywords: Boyle's Law; Gas Behavior; Experimental Method; Physics Education; Cookbook Practicum

Introduction

Practicum is essential in science learning as it helps students understand scientific concepts and skills. As an integral part of the learning process, practicum assists students in achieving learning objectives (Lutfhianti et al., 2024). Students not only learn theory during practical sessions, but they also have the opportunity to interact directly with physics concepts, which helps them learn more effectively and meaningfully (Marougkas et al., 2023). Practical sessions also help students acquire scientific skills necessary to understand the relationship between theory and practice. (Gomez-del Rio & Rodriguez, 2022) The kinetic theory of gases is one of the important concepts in physics that requires experimentation. Although the model is simplified, the theory provides important explanations of gas behavior, including the relationship of pressure and volume, which is described in (Putra et al., 2020) Boyle's law shows that at constant temperature, the relationship between pressure and volume of a gas is opposite (Laraudogoitia, 2022). Students often face difficulties due to the conceptual and microscopic nature of this theory. Not only theoretically important, an understanding of this law has many applications in the real world, such as in medicine, industry, and technology(Karimov et al., 2024).

Boyle's law can be represented mathematically as $P_1V_1 = P_2V_2$, (where P is pressure and V is volume) (Kahn, 2021), is a fundamental physical principle that explains how the pressure and volume of a gas at constant temperature and number of moles (Della Volpe & Siboni, 2022). This law says that an increase in gas volume will lead to a decrease in pressure at constant temperature and vice versa. It's not a perfectly linear relationship, but it's the right

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way to go for ideal gases in most situations(Zhang & Wang, 2022).

Many more complex physical phenomena are based on this simple idea. For example, the working principle of a propulsion device, such as the piston of a car engine, relies on the inverse relationship between pressure and volume described in Boyle's Law (Dragassi et al., 2023). The function of the lungs in the human respiration system relies on the same principle, where changes in the volume of the chest cavity cause changes in pressure, which allows air to enter and exit the lungs (Hakimi et al., 2022). In addition, Boyle's Law is a key principle behind many industrial processes, such as the operation of compressors and vacuum pumps (Rolo et al., 2024). Therefore, a comprehensive understanding of Boyle's Law, as a manifestation of the kinetic theory of gases, is essential for mastering physical science and provides valuable provisions for students in various fields of study (Kurczynski & Milojević, 2020).

For this reason, supporting the learning process with experimental tools is very important, especially when learning complex physics concepts. The Boyle's Law tool is specially made to learn and understand Boyle's law which states that the pressure of a gas will be inversely proportional to its volume in a closed system with a fixed temperature (Tomin & Kmetty, 2022) . The Boyle's Law tool allows students to manipulate the pressure and volume of a gas in a closed tube directly, allowing them to observe this phenomenon in impact. This tool generally consists of several important components, namely a manometer, a piston, and a closed tube (Rak et al., 2023) . The manometer serves to measure the pressure of the gas, while the piston allows adjusting the volume of the gas by changing the space inside the tube (Spaeth et al., 2022). The manometer is used to measure the pressure of the gas, while the piston allows the volume of the gas to be adjusted by changing the space inside the tube (Thakur et al., 2021). The closed tube plays an important role in keeping the gas in a closed system condition, so that the observation results are not influenced by external variables such as changes in temperature or air pressure outside the system. With this tool, students can more easily understand the basic concepts of Boyle's law through direct experimentation and visualization of the quantitative relationship between gas pressure and volume (Ali et al., 2022).

Through the use of Boyle's Law Apparatus, students not only conduct experiments, but are also invited to go deeper in analyzing the data obtained. They can observe how changes in gas volume affect pressure, and vice versa, and calculate relevant values from these observations (Akarsu, 2024). With the results of this experiment, students can draw more in-depth conclusions about gas behavior and the laws that govern it, such as Boyle's law itself. This understanding gained through direct experimentation is much more effective than simply reading theory (Wood & Laycraft, 2020). Furthermore, it allows students to explore variations in experimental conditions, such as switching gas volumes or changing pressure settings, which gives them the opportunity to explore how these factors interact with each other (Emmanuel et al., 2024). All of this provides a more interactive and immersive learning experience, which in turn supports a thorough understanding of the concept (Amanina et al., 2023).

However, the effective use of this tool is highly dependent on the structure of the lab guide provided. The cookbook approach, which offers detailed experimental steps, not only makes it easier for students to carry out the practicum but also helps them understand the basic concepts being studied (Idris et al., 2022). This approach also allows teachers and researchers to evaluate the performance of the tool as well as its effectiveness in supporting learning. With clear guidance, students can focus more on observation and analysis, instead of getting caught up in confusion regarding experimental procedures (Li et al., 2024).

This study aims to evaluate the effectiveness of using Boyle's Law Apparatus in Boyle's law practicum using the cookbook model approach. In addition, this study also examines the feasibility of implementing the

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apparatus in a school setting, focusing on technical constraints, student understanding, and necessary curriculum adaptations (Yafie et al., 2024). With the integration of a systematic experimental guide and an easy-to-use device, it is expected that this practicum can provide a meaningful learning experience for students. This research will hopefully provide insights into better teaching practices and assist teachers in designing a more effective curriculum for understanding physics.

The results of this study are expected to make a significant contribution to physics learning innovation, particularly in improving students' conceptual understanding of the ideal gas law and at the same time training their critical thinking skills. Thus, this research will not only provide benefits to physics education, but can also contribute to the development of scientific skills of future generations who will become problem solvers in various fields.

Methode

In this study, the experimental method was used to evaluate how effective the use of Boyle's law tool is in understanding the relationship between pressure and volume of a gas at constant temperature. This method was chosen because it allows the researcher to change the independent variable, which is gas pressure, and see how it impacts the dependent variable, which is gas volume. The aim of the data analysis was to find a pattern of the relationship between the pressure and volume of a gas at constant temperature. This research was conducted at MA Alinayah Bandung, involving four pressure variations modified using a vacuum pump and measured the volume for 10 trials per variation, a total of 40 trials.

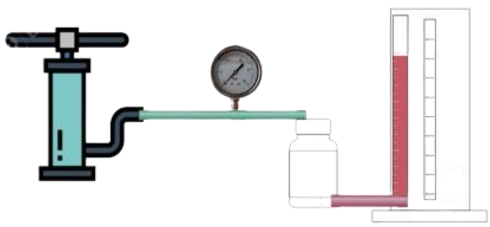

Figure 1. Sketch drawing of boyle's law experiment apparatus

Figure 2. Boyle's law experiment test

The instruments used include vacuum tubes, vacuum pumps, hoses, manometers, and volume meters, which allow accurate measurement of gas pressure and volume. Prior to the student experiment, the apparatus was tested by another group to ensure the accuracy of the apparatus and optimal performance. Each stage of the experiment is directly observed to collect data; pressure and volume values are recorded for each change in gas volume. To ensure consistent procedures and make it easier for students to understand the concepts taught, the practicum is conducted using the Cookbook practicum module guide.

Figure 3. Implementation of e school experiment tool

Result and Discussion

In this study, the volume of gas in a closed system is changed, while the pressure is measured using a manometer. This experiment is conducted using Boyle's Law tools, which include vacuum tubes, vacuum pumps, hoses, manometers, and volume meters.

The data obtained shows a consistent inverse relationship between gas volume and pressure. The experimental results show that the smaller the volume, the higher the pressure, and vice versa, in accordance with Boyle's Law which reads:

$$P \times V = konstan$$

Where:

P is pressure,
V is volume,
and constant is a value that remains at constant temperature.

To calculate the product between pressure (P) and volume (V), values were obtained at several experimental points. Here are the experimental data obtained in this experiment:

Tabel 1: Practicum Result Table

NO	Volume (mL)	Pump pressure Pa (kPa)	Manometer Pressure Pa (kPa)	Pressure Pm-Pa (kPa)	(Pm-Pa) V (kPa/mL)
1	34,5	220,4	111,25	109,15	3769,675
2	28,0	261,05	130,45	130,6	3668,8
3	24,0	300,5	150,15	150,40	3610,4
4	21,0	340,2	170,21	169,99	3569,79

The data shows the relationship between the product of pressure (P) and volume (V) of a fixed gas at constant temperature, according to Boyle's Law. It shows that the pump pressure increases from 220.4 kPa to 340.2 kPa when the volume drops from 34.5 mL to 21.0 mL. Although there are variations in the value of the product (P×V), the general pattern shows that this relationship remains constant. In other words, a decrease in volume leads to an increase in pressure, which confirms that when a gas is compressed, the pressure required to maintain that state also increases (Islami et al., 2020). This finding is important in the understanding of gas behavior and has practical applications in various fields, such as mechanical and industrial engineering, where the management of gas pressure is crucial. This result confirms the relevance of Boyle's Law in understanding the basic properties of gases in closed systems at a fixed temperature.

From the data obtained, we can draw a graph of the relationship between pressure (P) and volume (V), as well as a graph of the product P ×V. The following is an explanation of the resulting graph:

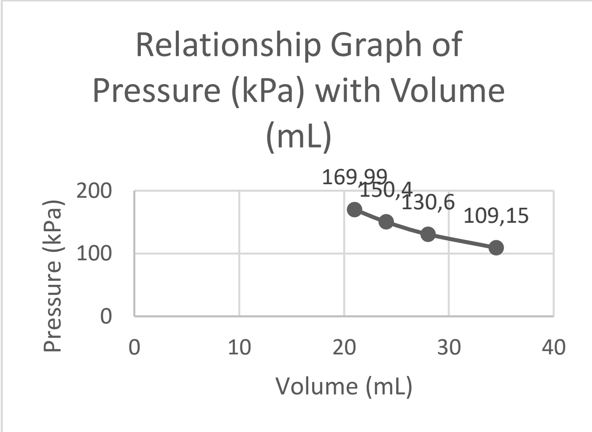

Figure 4. Graph of the relationship between Volume and Pressure

The graph clearly shows the inverse relationship between pressure and gas volume. As the volume of the gas decreases, it is seen that the pressure increases, which is represented as a decreasing curve on the graph. This is in line with Boyle's Law, which states that the product between pressure and volume remains constant at the same temperature. (Decollibus et al., 2023). The decreasing curve illustrates that as the gas is compressed and the volume decreases, the gas molecules get closer to each other, causing the speed and frequency of collision of the molecules with the container wall to increase, which in turn increases the pressure. As such, this graph effectively reflects the functional relationship between pressure and volume, providing a clear visualization of the nature of gas behavior.

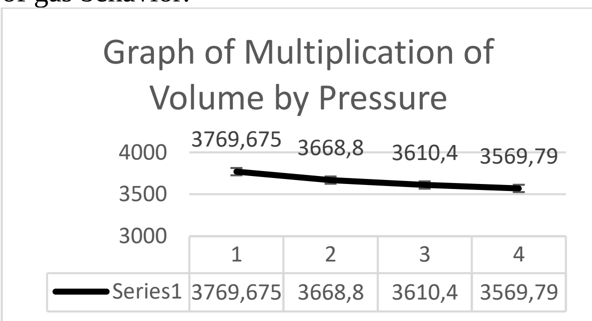

Figure 5. Graph of Multiplication of Volume by Pressure

This graph shows that the product P × V remains constant throughout the experiment, confirming that the relationship between pressure and volume of a gas is parallel to Boyle's Law. This observation is apparent when the value of the product of pressure (P) and volume (V) shows a tendency to remain stable, despite variations in the individual measured values of pressure and volume. In this context, as the gas volume decreases, the pressure increases, and vice versa, with the product of these two parameters remaining close to the same value throughout the experiment. This suggests that the gas behaves in accordance with the basic principle of Boyle's Law, which states that in a closed system at constant temperature, the product between the pressure and volume of the gas is constant. (Machin, 2024). Thus, these graphs not only reinforce the theory but also provide evidence that supports our understanding of the nature of gases under certain conditions.

The experimental results show an inverse relationship between pressure and volume based on Boyle's Law. The product P × V remains constant at a constant temperature confirming that this law applies in this experiment.

The experimental results agree with the theoretical predictions because the gas molecules collide with the container walls at a fixed temperature. As the volume of the container decreases, the distance between gas molecules becomes smaller, so the molecules collide more frequently, which causes the pressure to increase. Conversely, when the volume of the container is enlarged, the distance between gas molecules becomes larger, so the frequency of collisions decreases. (Al-attar, 2024).

The results of this experiment are in line with previous studies, such as those conducted by (Boyle & Banks, 2020), who found that by using simple tools in Boyle's Law experiments, data that matched the theory was generated. Although there were some minor discrepancies, such as inaccurate volume meter or manometer measurements, the data obtained still supported this law.

This study shows that tools such as manometers, volume meters, vacuum tubes, and vacuum pumps can be used in science learning to provide a deeper understanding of Boyle's Law. The structured cookbook method allows students to follow clear steps, reducing confusion and ensuring accurate data collection.

Future research could examine the use of more sophisticated tools, such as digital sensors or simulation software, to improve measurement accuracy in Boyle's Law experiments. In addition, further research could investigate how things such as temperature and humidity affect the results of the experiment, as well as how to reduce equipment operation errors that occur during the practicum.

Conclusion

In conclusion, this study successfully validated the effectiveness of using Boyle's Law Apparatus in demonstrating the inverse relationship between pressure and volume of gas at a constant temperature, in accordance with Boyle's Law. The experimental results consistently showed that as the volume of the gas decreased, the pressure increased, thereby supporting the hypothesis that P × V remains constant within a closed system. The structured cookbook method employed during the practicum not only facilitated accurate data collection but also enhanced students' understanding of the underlying principles governing gas behavior. This research emphasizes the importance of practical experimentation in science education, as it provides students with valuable hands-on experience and a deeper comprehension of physical concepts. Furthermore, it underscores the potential for utilizing such experimental tools in the classroom to cultivate critical thinking skills and foster a more interactive learning environment, thereby enriching the overall educational experience in physics.

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