# Experiment 1: Verification of Gas Laws

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# Introduction

Gases are defined as "having variable volume and variable shape". (Dr. Rashmi Venkateswaran,2018) Due to these characteristics, gases are the only form of matter that are dependent upon pressure, temperature and volume which can be examined through the Ideal gas law which states;

$$PV = nRT \quad [1]$$

Depending on which variables are kept constant, three laws arise from the ideal gas law: Charles' law, Boyle's law, and Avogadro's law (Silberberg, 2013). The goal of this lab is to test the relationship between the temperature, volume and the pressure of gases.

Charles' law explores the relationship between the volume and the temperature of a gas, keeping the pressure and the amount of the substance constant; it's demonstrating a linear relationship between the two variables (Sneblic, 2015):

$$V = mT \quad [2]$$

By testing this law, it is expected that if the temperature of the gas is to decrease, then the volume would decrease as well.

When rearranged in another way the Ideal gas law can express Boyle's Law as well;

$$P = \frac{nRT}{V} = \frac{k}{V} \quad [3]$$

Boyle's Law explores the relationship between the pressure and volume of a confined gas. For instance, when a fixed amount of gas is confined in a container and then the volume of the container changes the pressure caused by the gas will change as well. (Andersen, 2011 ) To better examine this relationship Boyle's Law can be further simplified when the temperature (T), amount of substance (n) remain constant resulting in the following expression;

$$P_1 * V_1 = P_2 * V_2 = k \, [4]$$

From this expression, it can be expected that as the volume of a confined gas decreases its pressure will increase and vice versa as their constants must equal one another. This theory will be analyzed in further depth throughout this lab report.

Overall both Charles's Law and Boyle's Law are dependent upon the Ideal Gas model. Yet, the ideal gas model is indeed ideal and doesn't reflect the reality of gas behavior at all times. The ideal gas model is based on two assumptions that differ from the real gas behavior:

1. The gas is made up of point particles which do not have a determined volume
2. There are no intermolecular forces acting between the gas particles.

These assumptions allow for an accurate explanation of gas behavior under the normal conditions; however, as the gas approaches its condensation point (under extreme conditions of high pressures or low temperatures) the ideal gas model becomes less accurate and begs for revision. In this lab, the temperature of the gas has been kept at the room temperature, and the pressure was manipulated within the normal range, thus the ideal gas law should be relatively applicable in this lab.

*References:*

Silberberg, Chemistry, Non-ideal Gases: Deviation from Ideal Behaviour, 2013, pp.183.

Dr. Rashmi Venkateswaran, Verification of Gas Laws, 2018.

Andersen, Nobile, Cormas, Science Scope, Vol. 35, No. 1, 2011, pp. 60-63.

Sneblic, Milisavljevic, Fizika 2, Idealni Gas, 2015, pp.115-119

# Procedure for Charles's Law

As described in lab manual (Dr. Rashmi Venkateswaran, Verification of Gas Laws, 2018)

# Procedure for Boyle's Law

Safety: Wear a lab coat and goggles at all times

1. Connect Gas Pressure Sensor to LabQuest2
2. Set an initial volume on the plastic 20ml syringe
3. Connect the 20ml plastic syringe to the gas pressure sensor with a one-half turn to lock it in place
4. Collect data points by moving the plunger in set increments
5. Collect 6-8 data points
6. Repeat Steps 2-5 at least once for a minimum total of two trials with various initial volumes and increments.

# Data and Observation/Results

Table 1. Data and Results in Verifying Charles's Law

| **Trial 1** | | |
|---|---|---|
| Volume (ml) | Temperature (K) | m(ml/K) |
| 147.8 | 374.35 | 0.3948 |
| 115.8 | 279.15 | 0.4148 |
| Percent error: 5.069% | | |
| **Trial 2** | | |
| 154.1 | 377.15 | 0.4086 |
| 120.3 | 280.05 | 0.4296 |
| Percent error: 5.134% | | |
| | **Average m value:** | 0.4120 |

Table 1. Data and Results in Verifying Charles's Law

Qualitative observations for Charles's Law:

- There was no colour change, sound or smell observed.
- Difficult to prevent air from escaping flask when transferring into the ice bath

| Data Points | Run 1 | | | Run 2 | | | Run 3 | | | Run 4 | | | Run 5 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Volume (ml) | Pressure (kPa) | Constant k | Volume (ml) | Pressure (kPa) | Constant k | Volume (ml) | Pressure (kPa) | Constant k | Volume (ml) | Pressure (kPa) | Constant k | Volume (ml) | Pressure (kPa) | Constant k |
| 1 | ~~0.80~~ | ~~103.94~~ | ~~83~~ | ~~15.80~~ | ~~100.31~~ | ~~1585~~ | ~~20.80~~ | ~~100.27~~ | ~~2986~~ | ~~20.80~~ | ~~100.27~~ | ~~2086~~ | ~~0.80~~ | ~~103.76~~ | ~~83.0~~ |
| 2 | 2.80 | 20.62 | 57.7 | 12.80 | 121.32 | 1553 | 15.80 | 131.46 | 2077 | 18.80 | 111.18 | 2090 | 2.80 | 19.87 | 55.6 |
| 3 | 4.80 | 11.37 | 54.6 | 9.80 | 159.66 | 1560 | 10.80 | 185.48 | 2003 | 16.80 | 124.58 | 2093 | 4.80 | 8.91 | 42.8 |
| 4 | 6.80 | 11.50 | 78.2 | 6.80 | 224.74 | 1530 | 7.80 | 224.74 | 1750 | 14.80 | 141.25 | 2090 | 6.80 | 7.55 | 51.3 |
| 5 | 8.80 | 8.50 | 74.8 | 3.80 | 224.73 | 854 | 20.80 | 101.00 | 1991 | 12.80 | 161.86 | 2072 | 8.80 | 6.14 | 54.0 |
| 6 | 10.80 | 6.68 | 72.1 | 15.80 | 100.01 | 1580 | | | | 10.80 | 194.04 | 2096 | 10.80 | 5.14 | 55.5 |
| 7 | 0.80 | 128.77 | 100 | | | | | | | 8.80 | 224.73 | 1980 | 12.80 | 4.60 | 58.9 |
| 8 | | | | | | | | | | 20.80 | 100.73 | 2100 | 14.80 | 4.13 | 61.1 |
| 9 | | | | | | | | | | | | | 16.80 | 3.87 | 65.0 |
| 10 | | | | | | | | | | | | | 18.80 | 3.60 | 67.7 |
| 11 | | | | | | | | | | | | | 20.8 | 3.76 | 78.2 |
| 12 | | | | | | | | | | | | | 0.80 | 87.83 | 70. |
| | | Average k | 73 | | Average k | 1.4x10^3 | | Average k | 2.0x10^3 | | Average k | 2.1x10^3 | | Average k | 60 |

Table 2. Data and Results in Verifying Boyle's Law

Qualitative Observations for Boyle's Law:

- There was no colour change, smell or sound observed
- Difficult to increase the fixed volume of the syringe when starting data point was less than 5.8ml
- Took awhile for pressure to stabilize

# Graphs

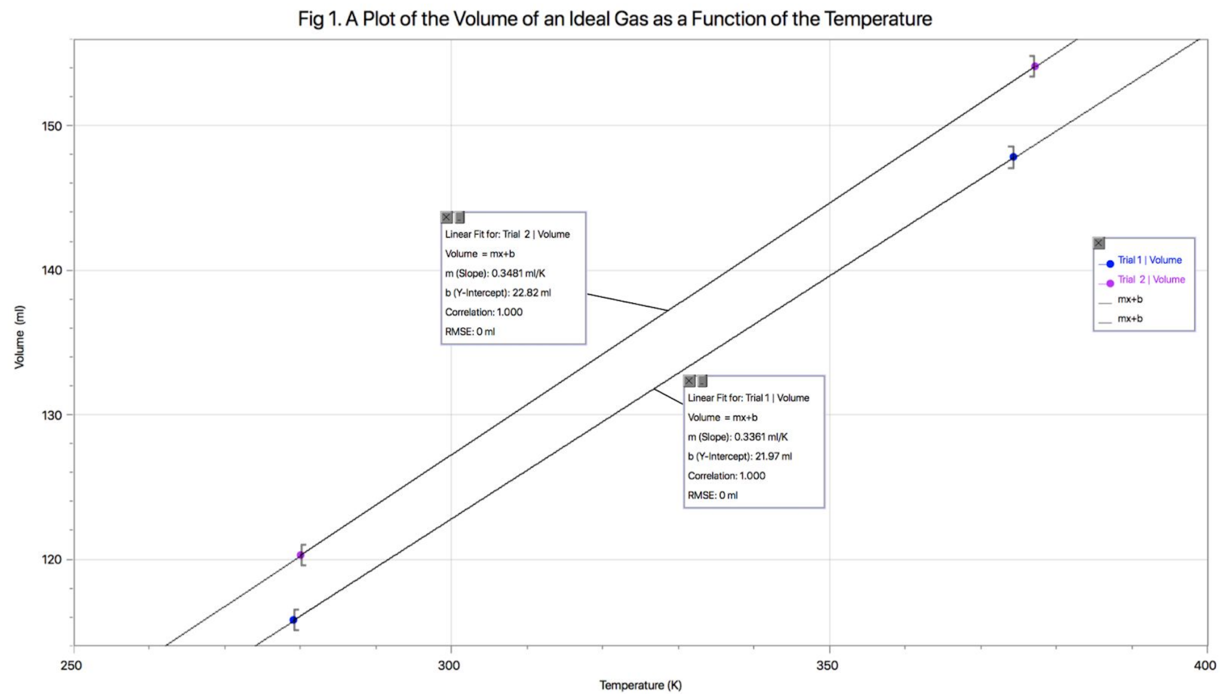


Figure 1.  A Plot of the Volume of an Ideal Gas as a Function of the Temperature

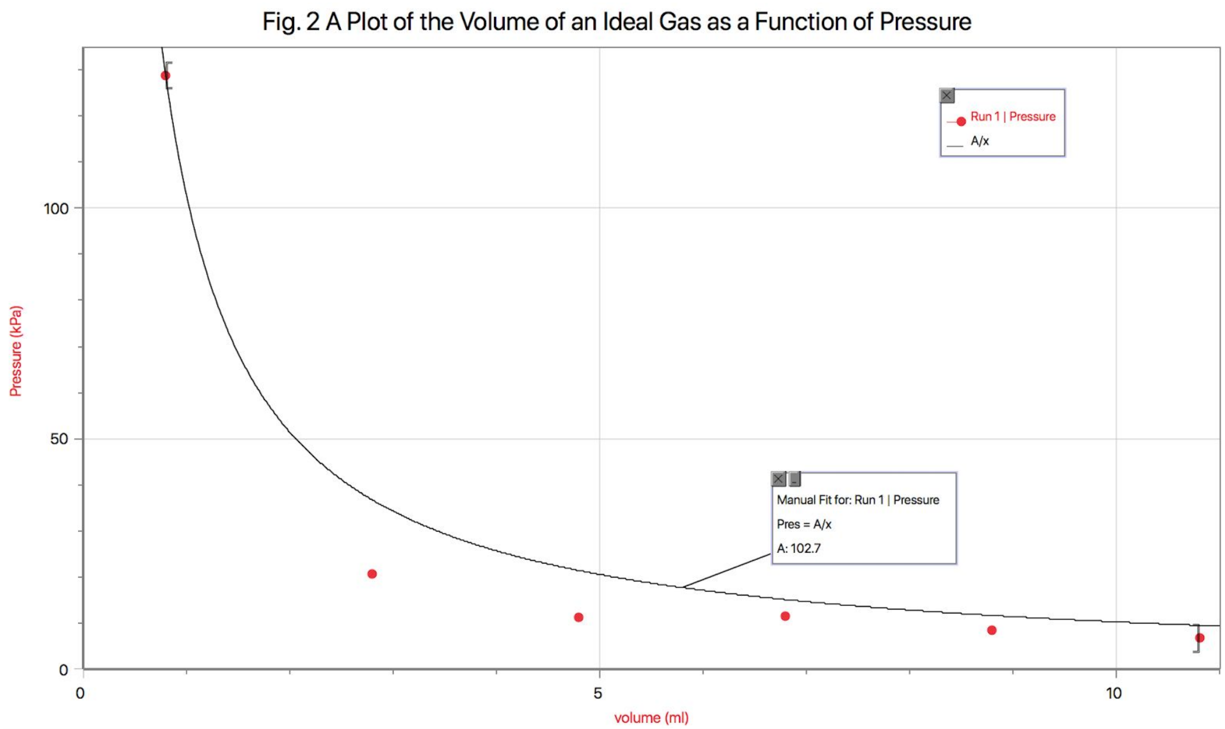


Figure 2. A Plot of the Volume of an Ideal Gas as a Function of Pressure

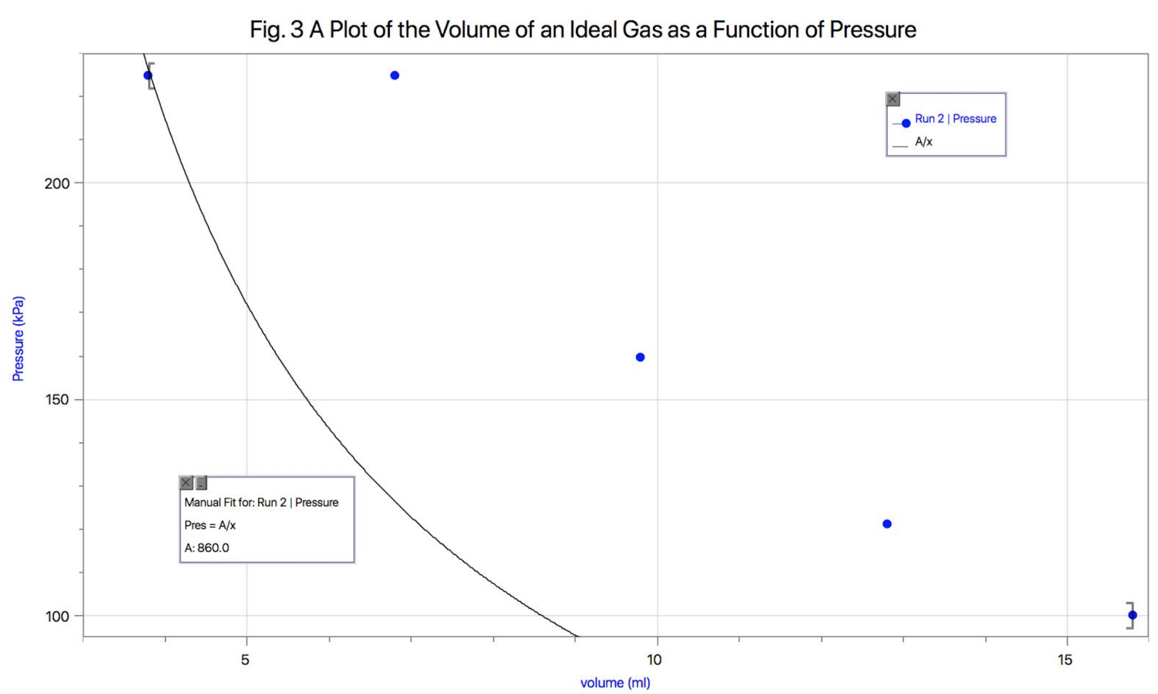


Figure 3. A Plot of the Volume of an Ideal Gas as a Function of Pressure

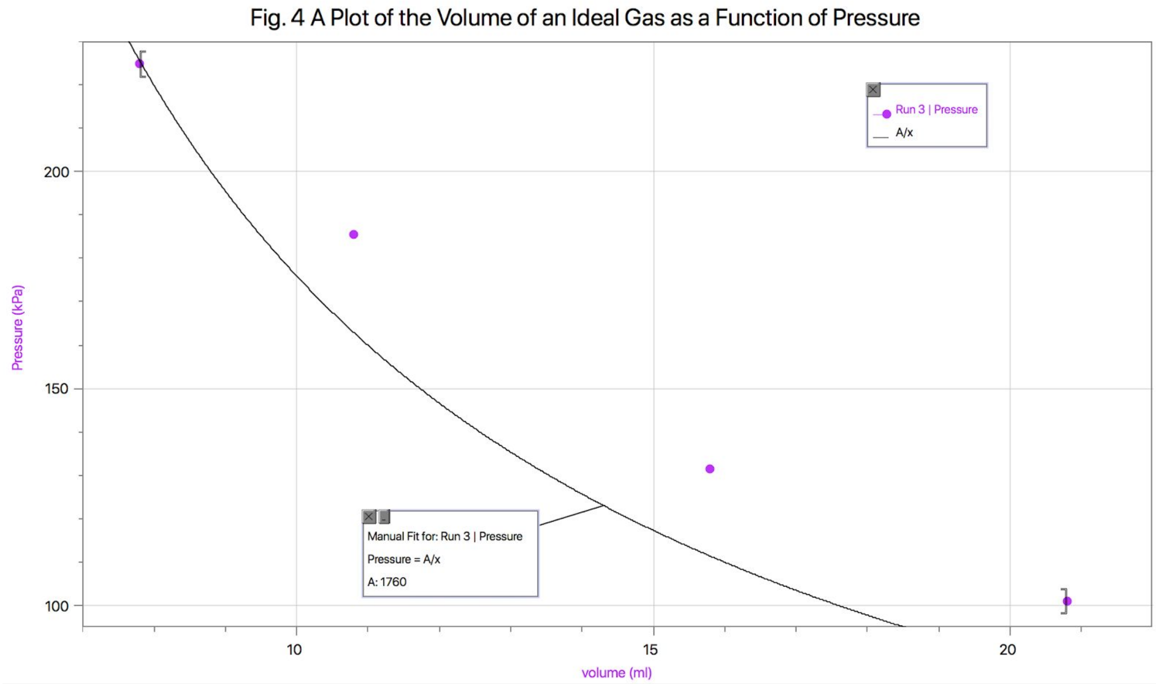


Figure 4. A Plot of the Volume of an Ideal Gas as a Function of Pressure

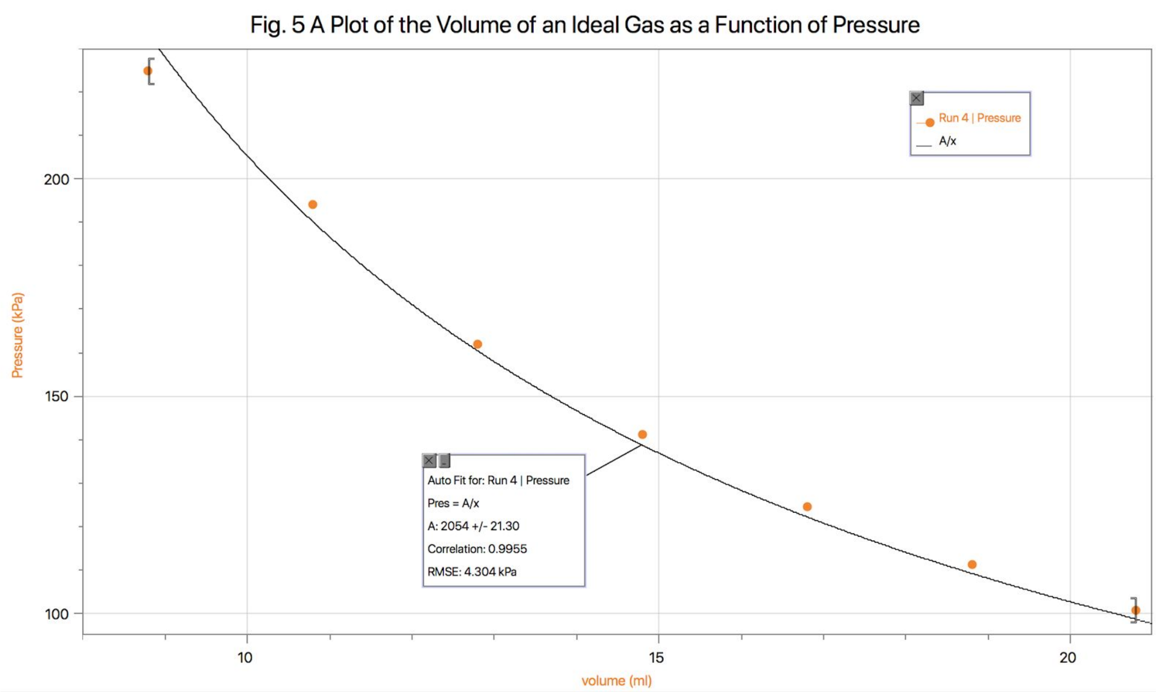


Figure 5. A Plot of the Volume of an Ideal Gas as a Function of Pressure

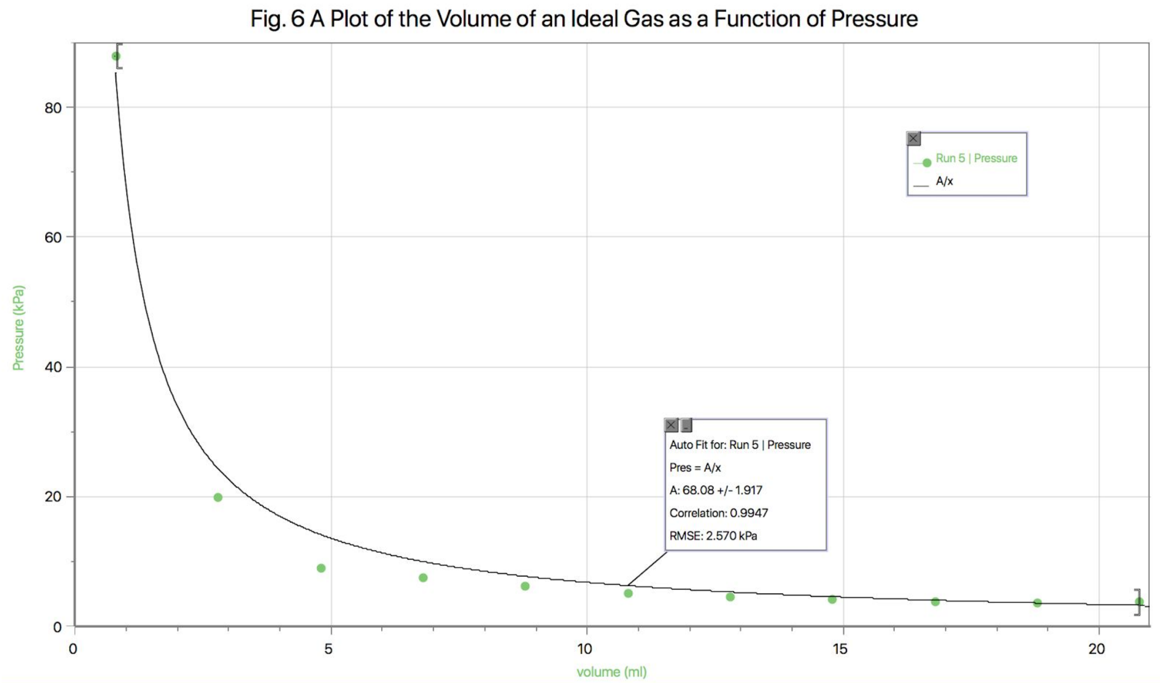


Figure 6. A Plot of the Volume of an Ideal Gas as a Function of Pressure

# Calculations

## Charles' Law

To confirm Charles' Law $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

Trial 1

$V - volume$

- $V_1 - volume\ 1\ in\ trial\ 1$
- $V_2 - volume\ 2\ in\ trial\ 1$

$T - temperature$

- $T_1 - temperature\ 1\ in\ trial\ 1$
- $T_2 - temperature\ 2\ in\ trial\ 1$

$m - constant$

- $m_1 = \ constant\ for\ volume\ 1\ and\ temperature\ 1\ in\ trial\ 1$
- $m_2 = \ constant\ for\ volume\ 2\ and\ temperature\ 2\ in\ trial\ 1$

$V_1 = 147.8\ ml$
$T_1 = 101.2℃ = 374.35K$
$V_1 = m * T_1$
$m_1 = \frac{V_1}{T_1} = \frac{147.8ml}{374.35K} = 0.3948$

$V_2 = V_1 - V_{CW} = 147.8\ ml - 32.00ml = 115.8ml$
$T_2 = 6.0℃ = 279.15K$
$V_2 = m * T_2$
$m_2 = \frac{V_2}{T_2} = \frac{115.8ml}{279.15K} = 0.4148$

$m = (m_1 * m_2)/2 = 0.4120$

Percent error for Trial 1:

$$\% = \frac{\frac{V_1}{T_1} - \frac{V_2}{T_2}}{\frac{V_1}{T_1}} * 100\% = |-5.068935103|\,\% = 5.069\%$$

Percent error for Trial 2:

$\% = 5.134\%$

## Boyle's law

To confirm Boyle's Law $P_1 * V_1 = P_2 * V_2 = k$

Trial 4

$P - pressure$

- $p_7 - data\ point\ 7\ in\ trial\ 4$
- $p_5 - data\ point\ 5\ in\ trial\ 4$

$V - volume$

- $V_7 - data\ point\ 7\ in\ trial\ 4$
- $V_5 - data\ point\ 5\ in\ trial\ 4$

$k - constant$

- $k_4 - constant\ for\ trial\ 4$

$P_7 = 1.73\ kPa$
$V_7 = 20.8\ ml$

$P_5 = 194.04\ kPa$
$V_5 = 10.8\ ml$

$P_7 * V_7 = P_5 * V_5 = k_4$
$1.73\ kPa * 20.8\ ml \approx 194.04\ kPa * 10.8\ ml \approx k_4$
$21.0 * 10^1 \approx 21.0 * 10^1 \approx k_4$

$k = (k_1 + k_2 + k_3 + k_4 + k_5)/5 = 1122.653255 \approx 1100$

# Discussion

The Charles' law experiment data has confirmed the initial hypothesis: If the temperature of a gas is changed, then the volume of the gas will be changed as well. Once the Erlenmeyer had been filled with air, heated up, placed into an ice bath and allowed to cool down, the flask filled up with water indicating that the air inside of the Erlenmeyer had contracted and occupied a smaller volume. The relationship between the two variables can best be demonstrated by a linear function $V = mT$. In Figure 1. the two lines representing the relationship between volume and pressure in each of the trials appear to be almost parallel, indicating that the rate of change is the same in both trials. There is a linear relationship between the volume and the pressure of the gas, described by the constant m (the slope). Based on the data gathered, the constant value was calculated to be 0.4120.

Regardless of the overall success of the experiment, a few challenges were encountered that have possibly become sources of error calculated above. Possible sources of error were:

1. When measuring the temperature of the hot air inside the Erlenmeyer, the thermometer wasn't able to fit inside the small hole inside the plunger in order to record the gas' temperature; instead, the temperature of the hot water surrounding the Erlenmeyer was recorded and was assumed to be the same temperature as the temperature of the gas. The problem following such assumption is that the Erlenmeyer wasn't fully submerged in the hot water nor

was it kept in the hot water long enough for its temperature to be fully equated with the one of the hot water.

2. During the 2nd trial, there is a possibility that the Erlenmeyer wasn't completely dried and still contained some drops of water from the previous trial, affecting the further volume recordings.
3. The tape indicating the end of the plunger and the beginning of the Erlenmeyer became wet and possibly moved around slightly throughout the trial.

The Boyle's law experiment data has confirmed the initial hypothesis: If the volume of a confined gas is changed, then the pressure of the gas will be changed inversely as well. All trials were expected to demonstrate an inverse relationship between the volume and the pressure of a fixed gas as assumed in the introduction and shown in our calculations and graphs. In Figures 2-6 The lines of best fit in each of the trials appear to correspond the best with a graph of an inverse function, indicating an inverse relationship between the pressure and the volume of a gas, described by a constant k.

Due to this inverse relationship, the first data point was tested twice in each trial to confirm that as the volume of a fixed gas decreases its pressure will increase and vice versa. It is important to take multiple readings of the dependent variable for the same value of the independent variable to eliminate possible sources of error and to verify the relationships between the dependent and independent variables. Hence, the second first data point was kept throughout all trials. Unfortunately for trials 2 and 3, their lines of best fit did not correspond with an inverse function. This observation could have been caused by systematic and random errors respectively such as;

1. decreasing the fixed volume of the syringe from a high starting data point to a data point less than 5.8ml as it was hard to physically keep in place while the pressure stabilized.
2. not collecting enough data points in a trial as there wouldn't be enough tangible points to analyze

In order for Boyle's law to demonstrate this inverse relationship, certain conditions must be met such as having a constant temperature and mass of the gas in question. Throughout this lab, these variables were taken into consideration however no action was taken to ensure they remained constant. Since the lab was performed in an educational setting it can be assumed that the temperature of the room will remain constant throughout the lab hence, the temperature of the gas will remain constant as well. Also since the gas was enclosed in a plastic syringe no thermometer probe was able to reach the gas making it difficult to monitor. In terms of the mass of the gas, since the initial mass of the ideal gas in the syringe creates a vacuum it can be assumed that the mass will remain constant. Overall, these variables did not affect our results greatly as all runs demonstrated that as volume increases pressure decreases.

# Conclusion

The experiment confirms Charles' law and the initial hypothesis: if the temperature of the gas was to decrease, then the volume would decrease as well. Charles' constant was determined to be 0.4120. The experiment also confirms Boyle's law and the inverse relationship associated with it, supporting the initial hypothesis: If the volume was to decrease the pressure would increase. The Boyle's constant was determined to be 1100.