Verification of Gas Laws

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September 18, 2018

Introduction

Boyle's Law outlines the relationship between the volume and pressure of a gas, while Charles' Law outlines the relationship between the volume and temperature of a gas; the goal of this experiment is to prove these universally accepted laws[3]. Robert Boyle was a famous Irish physicist/chemist who discovered in the mid 1600s that the volume and pressure of an ideal gas, while kept at a constant temperature, with a fixed number of moles, are inversely proportional to each other[2]. This proportionality is now known as Boyle's Law, shown as:

$$V \propto (1/P) \tag{1}$$

V=Volume, P=Pressure

The theory behind this law states that when the temperature and amount of an ideal gas are kept constant, as the volume of it is decreased, its pressure will increase (at an inversely proportional rate) and vice-versa[3]. Boyle's law can be represented as a constant which is the product of the gas's volume and pressure such that:

$$V * P = k \tag{2}$$

k= constant

From this formula, it is understood that the constant is true for all values of pressure and volume of a specific ideal gas. This means that the product of the initial volume and pressure of a gas is equal to the product of its final volume and pressure[1]. This formula is represented as:

$$V_1 * P_1 = V_2 * P_2 \tag{3}$$

Boyle's law increases the understanding of behaviours of gasses and has multitudes of practical applications such as its presence in the use of syringes. This experiment's goal is to prove Boyle's Law by testing the pressure of a gas at varying volumes. Since this law is meant to apply to an ideal gas, which is not the case most of the time, some slight errors are to be expected. It is assumed that the Boyle's Law constant calculated for the three trials will be the same or very close.

Jacques-Alexandre-César Charles was a French physicist, who's famous discovery of the relationship between an ideal gas's temperature and volume for some fixed amount, added to the understanding of the behaviours of gasses[4]. His work involved quantitative studies involving this relationship, through which he discovered that when controlled, an ideal gas's volume and temperature are directly proportional such that:

$$V \propto T \tag{4}$$

T=Temperature

This proportionality can be represented as a constant which is the quotient of volume and temperature of a specific ideal gas such that:

$$V/T = k \tag{5}$$

Similar to the Boyle's Law equations, the quotient of volume and temperature for a specific ideal gas are conserved when all other variables are kept constant such that:

$$V_1 / T_1 = V_2 / T_2 \tag{6}$$

Charles' Law furthers the understanding of gasses and has universal applications that are crucial to the functioning of many devices such as a hot air balloon. This experiment seeks to confirm Charles' Law, but since gasses do not act ideally, some experimental errors are expected. It is assumed that the Charles' Law constant calculated for the two trials will be the same or very similar.

Procedure

Charles' Law: See lab manual for Experiment 1, "Do I Dare Disturb the Universe" (T.S. Eliot) – Verification of Gas Laws, pages 7-8.

Boyle's Law: See lab manual for Experiment 1, "Do I Dare Disturb the Universe" (T.S. Eliot) – Verification of Gas Laws, pages 8-10.

Revisions:

1. Start the plunger on the syringe at 20mL with the plunger line closest to the open end of the syringe.
2. Decrease the volume by 2mL each time and keep the pressure data each 2mL decrease.
3. Take the data up to 14mL from the zero-point (20mL), then take the zero-point (20mL) data once again to verify that no air left the system.
4. Repeat this process three times to verify the validity of the data.

For Verification see 'Raw Data' section of this report.

Observations

Charles' Law:

- Once the Erlenmeyer was placed upside down (in the ice bath) and the finger was released, water rushed in.
- First test, temperature needed to be measured for longer.

Boyle's Law:

- Once plunger reached 14mL, the pressure leveled out (likely due to limitations of the pressure sensor).

Tables

Charles' Law:

	Trial 1	Trial 2
V_1 (mL)	148	148
T_1 (°C)	68.8	92.7
V_2 (mL)	95.1	110
T_2 (°C)	5.8	5.2
V_{cw} (mL)	52.9	38

Table 1: Initial and final volumes and temperatures for trials 1 and 2

Boyle's Law:

Volume (mL)	Trial 1: Pressure (kPa)	Trial 2: Pressure (kPa)	Trial 3: Pressure (kPa)

20.8	102.36	102.36	102.21
18.8	114.03	113.58	114.86
16.8	127.74	126.94	128.75
14.8	145.70	144.92	146.02
12.8	167.57	169.01	169.60
10.8	200.18	200.20	199.38
8.8	226.01	226.03	226.04
6.8	226.01	226.03	226.04

Table 2: Volumes and associated pressures for trials 1 through 3

Graphs

Charles' Law

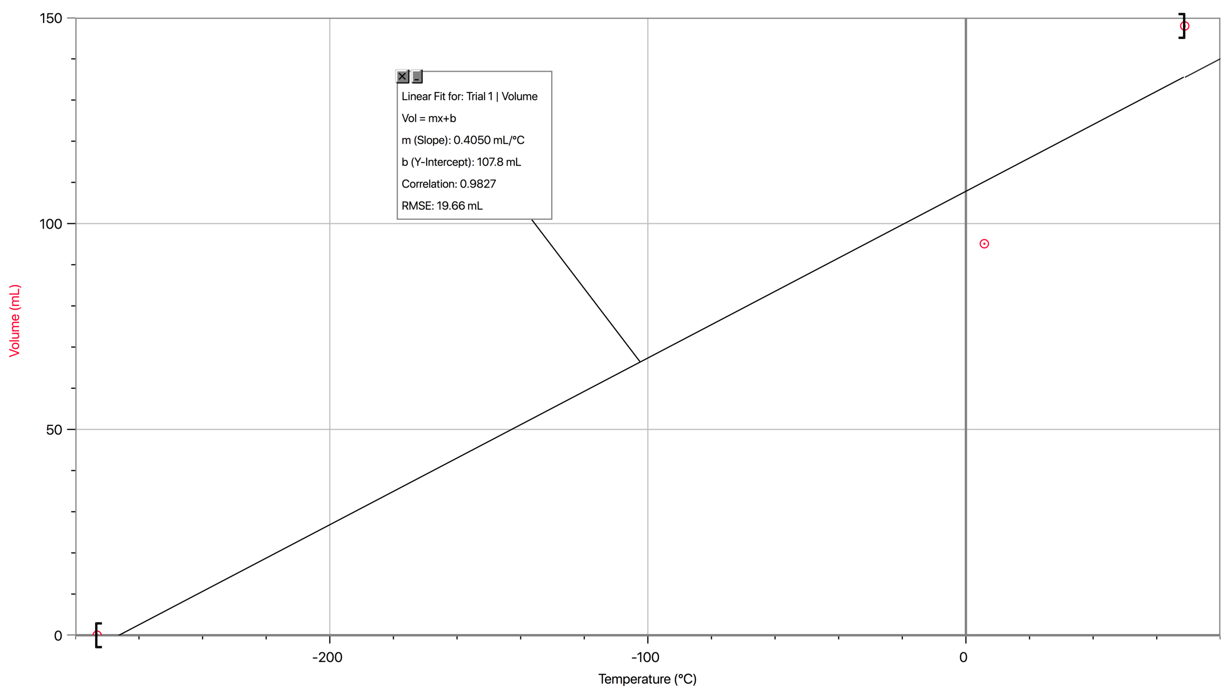


Figure 1: Charles' Law graph, trial 1

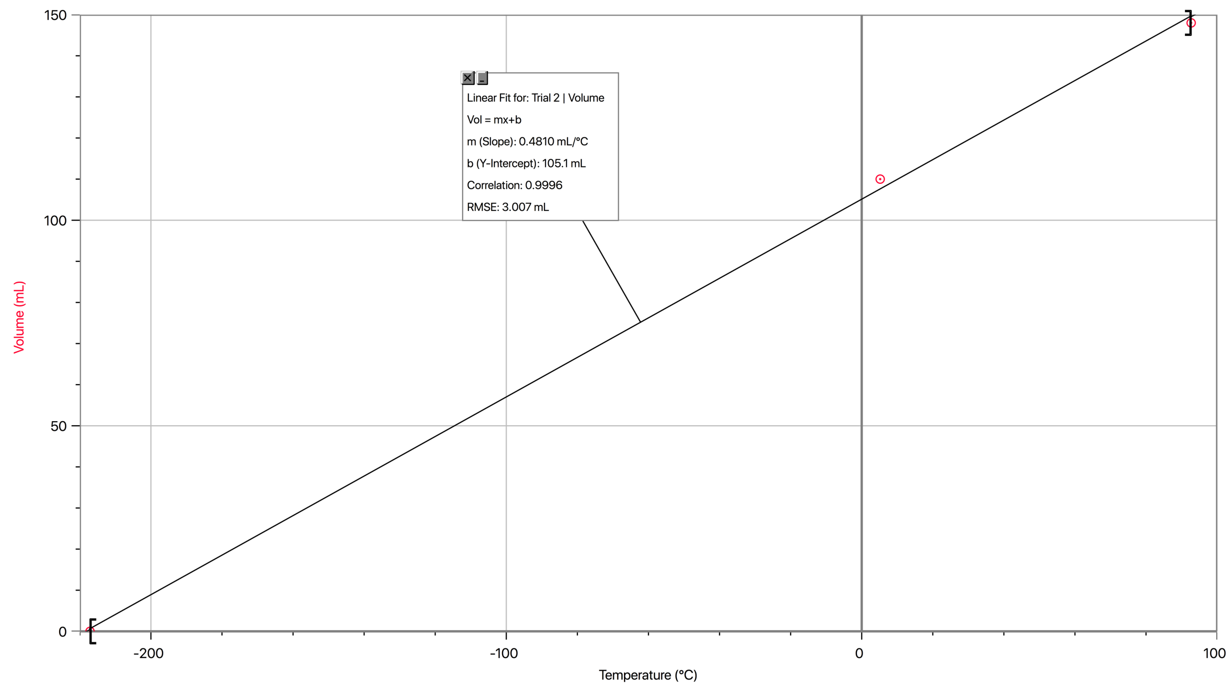


Figure 2: Charles' Law graph, trial 2

Boyle's Law

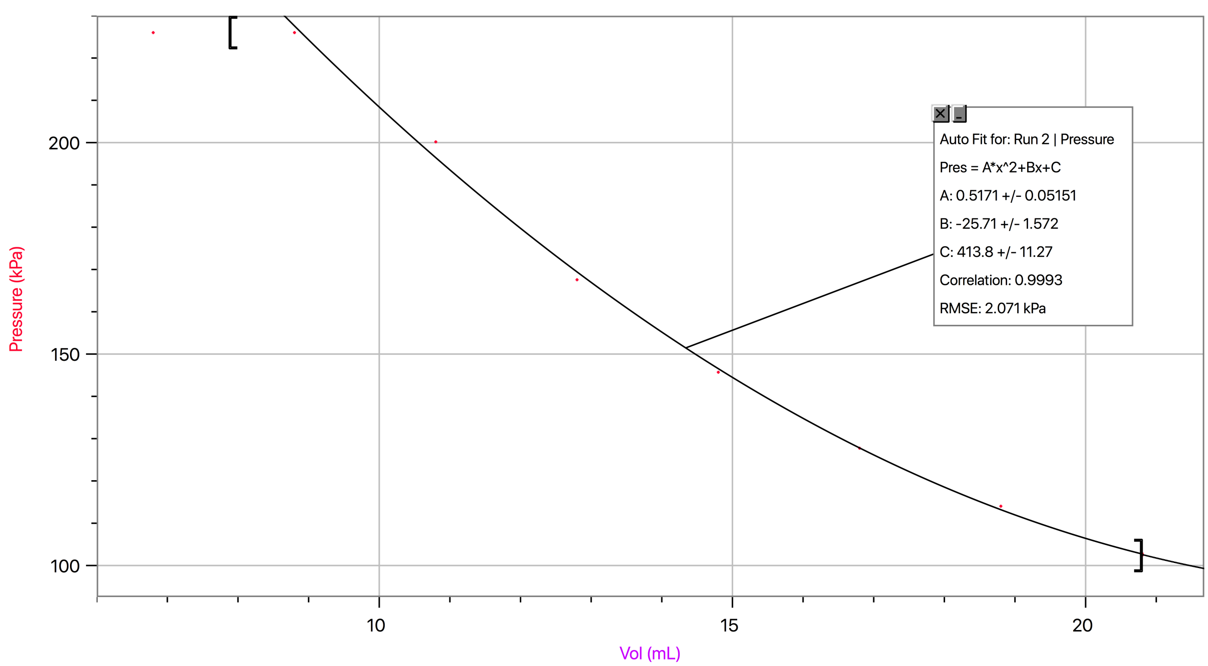


Figure 3: Graph for Boyle's Law relationship, trial 1

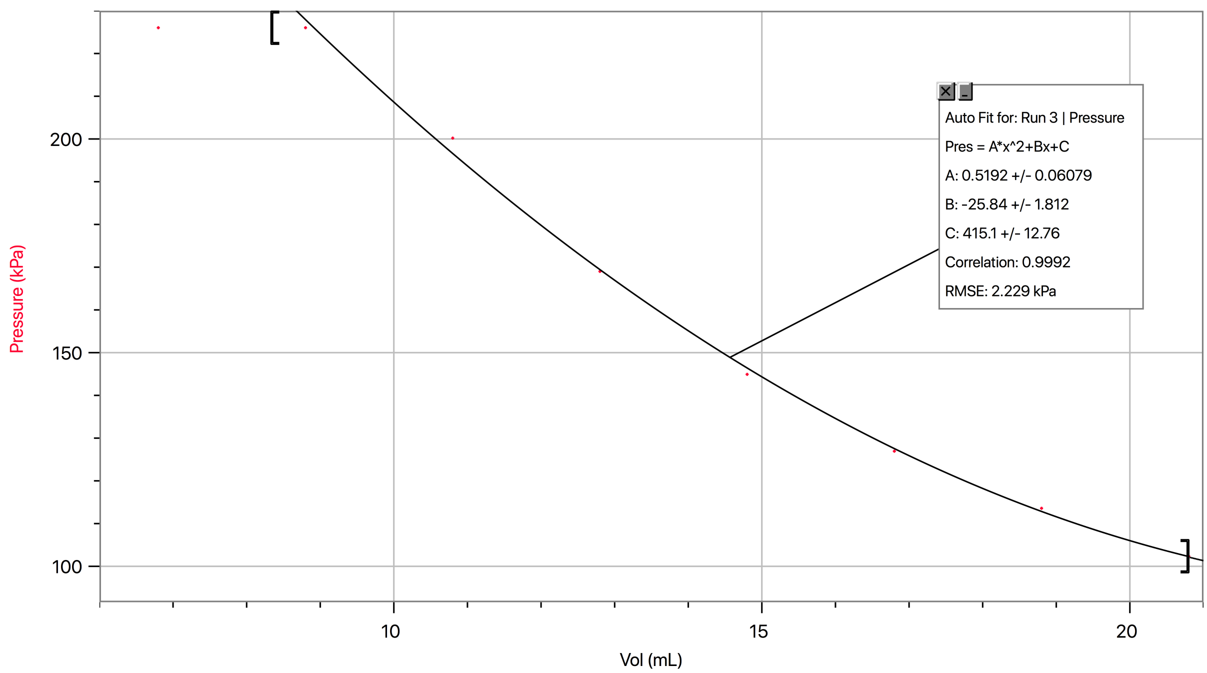


Figure 4: Graph for Boyle's law relationship, trial 2

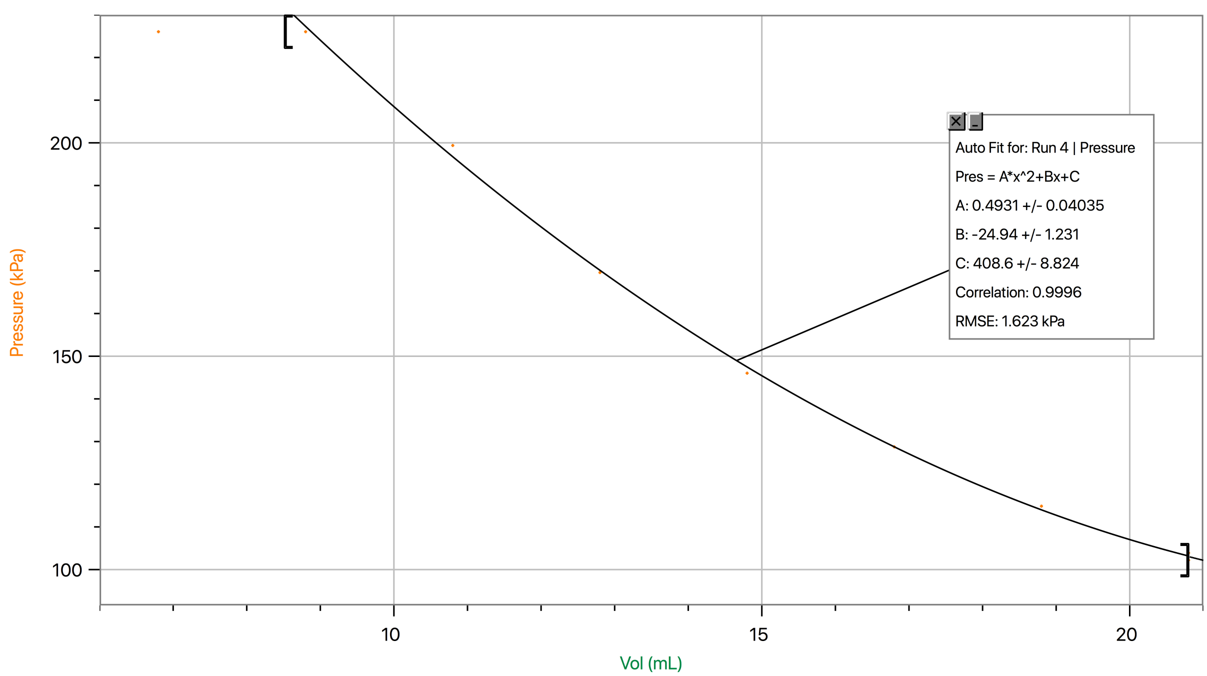


Figure 5: Graph for Boyle's law relationship, trial 3

Calculations

Boyle's Law Constant:

$$(P_1 * V_1 + P_2 * V_2 + \ldots + P_7 * V_7) / 7 = \text{Average Boyle's Law constant} \quad (7)$$

$$= (102.36kPa * 20.8mL + 114.03kPa * 18.8mL + \ldots + 226.01kPa * 8.8mL) / 7$$

$$= 2.1x10^3 mL•kPa$$

Charles' Law Constant:

$$V_1 / T_1 = V_2 / T_2 \quad (6)$$

$$(148mL / (68.8°C + 273.15)) = (95.1mL / (5.8°C + 273.15))$$

$$0.433mL/K = 0.34mL/K$$

convert temperature to kelvin for calculation

% Error for Charles' Law:

$$\% \text{ Error} = [((V_1 / T_1) – (V_2 / T_2)) / (V_1 / T_1)] x100\% \quad (8)$$

$$\% \text{ Error} = [(0.433mL/K – 0.34mL/K) / 0.433mL/K] x 100\%$$

$$\% \text{ Error} = 21\%$$

Average Charles' Law Constant:

$$\text{Average constant} = [(V_1 / T_1) + (V_2 / T_2)] / 2 \quad (9)$$

$$[(0.405mL/K) + (0.40mL/K)] /2 = 0.40mL/K$$

Discussion

The experiment for Boyle's Law was successful in that it confirmed that the volume and pressure are inversely proportional for a fixed amount of gas, at a constant temperature. It was expected that the constants would be the same or at least very close (when considering errors), and this expectation was clearly met. The average Boyle's Law constants for trials 1, 2, and 3 are $2.1x10^3$mL•kPa, $2.1x10^3$mL•kPa, and $2.1x10^3$mL•kPa respectively (accurate to 2 significant figures). The data for the three trials is extremely close, and effectively represent Boyle's proportionality of pressure and volume of an ideal gas. The ambient temperature during the experiment was kept constant by the thermostat in the room, but negligible variations may have occurred during the experiment. The amount of gas was kept fixed by an air-tight seal on the pressure sensor.

When measuring the initial volume for the second time (to check for any lost air), the difference was negligible and so those secondary data points could be discarded. As for the pressure reading at the 6.8mL volumes, the gas-pressure-sensor was unable to calculate its pressure and leveled it out at the same value as the reading for the previous volume. For this reason, those values were also discarded for the calculations of the Boyle's Law constants and the lines of best fit for the graphs of the data.

There were sources of error that may have affected the accuracy of the data that was measured during the lab. Firstly, Boyle's Law is meant to be used for ideal gasses, but in reality, gasses do not behave ideally, and this fact causes the pressure sensor to fluctuate between decimal places of the value shown, so this fact may have caused slight inaccuracies in the measurement of pressure. This type of error is expected, and its impact is so miniscule that it does not require fixing. Another source of error was the resistance of the syringe at higher pressures being very substantial, which made it difficult to hold the plunger steady at the desired volume. This could have affected the accuracy of the pressure readings by a few decimal places, which is not very concerning to the overall accuracy of the test. In order to fix this problem, a device that is able to automatically change the volume in the syringe, with greater accuracy than that of a human, could be used (ultimately removing human error in measurement as well).

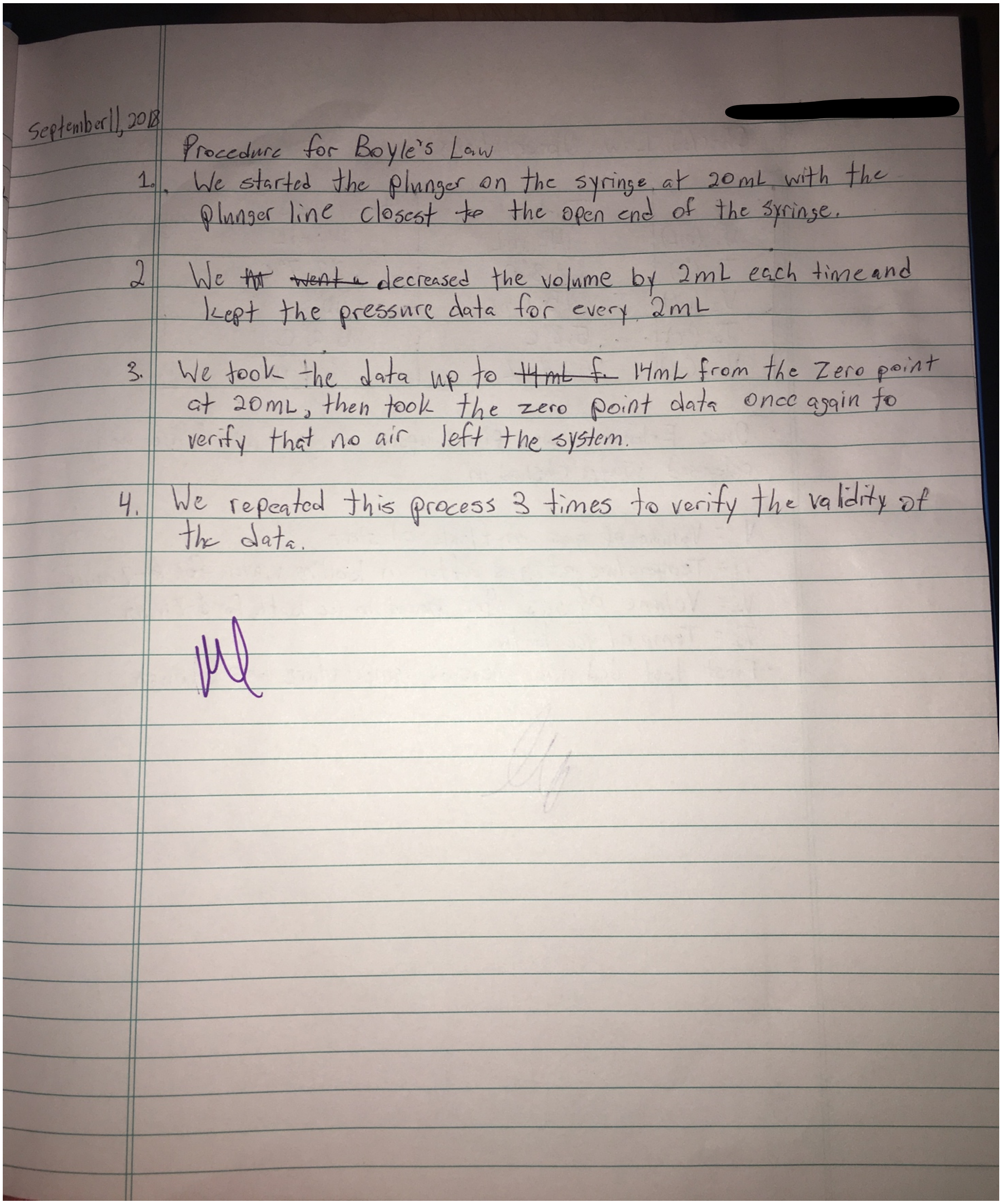
The experiment for Charles' Law was successful in confirming the direct proportionality between an ideal gas's volume and temperature (for a fixed amount and pressure) with minor inaccuracies due to sources of error. It was expected that for both tests, the initial and final Charles' Law constants would be the same, if not, very similar, and the results of the experiment display these conclusions. For trial 1, the initial constant was 0.433mL/K whereas its final constant was 0.34mLmL/K. For trial 2, the initial constant was 0.405mL/K and the final constant was 0.40mL/K. The first trial had a 21% error value and the second trial had a 1.2% error value. This means that trial 2 was extremely accurate and its data can be used to display the direct proportionality between volume and temperature of an ideal gas. To further illustrate, Figure 2 shows the two points calculated and the point at absolute zero. All of the points are extremely close to the line of best fit, which shows that temperature and volume have a linear relationship. Using this accurate data, the average Charles' Law constant is then 0.40mL/K.

There were sources of error in the lab that caused the % error of the trials to deviate from 0%. Firstly, like Boyle's law, this relationship is defined for ideal gasses which do not occur in reality. This causes negligible effects and are expected in such an experiment. A more substantial source of error is that the measurement of the initial temperature for trial 1 needed a longer time to calibrate. The temperature reading from the probe device takes a long time to rise, and the temperature was read too early, leaving an inaccurate (too low) initial temperature. This caused the difference between the initial constant and the final constant to be greater, ultimately raising the % error for trial 1. The improvement to make for next time is to measure the temperature for a longer time, to allow it to rise to its true peak. Finally, the measurement of water is not as accurate as it could be, because when transferring the water from the Erlenmeyer flask to the graduated cylinder, there could be some excess water left in the flask that was not measured. This would raise the value for the final volume of gas, effectively changing the final Charles' Law constant. In order to more accurately measure the volume of the gas, a gas-volume measuring instrument could be used instead.

Conclusion

The hypotheses for both the Boyle's Law and Charles' Law experiments were confirmed based on the data that was recorded, while considering the sources of error. The average Boyle's Law constant was determined to be 2.1×10^3mL•kPa, and the average Charles' Law constant was determined to be 0.40mL/K.

Raw Data



September 11, 2018 [redacted]

Procedure for Boyle's Law

1. We started the plunger on the syringe at 20mL with the plunger line closest ~~to~~ the open end of the syringe.

2. We ~~Att~~ ~~went~~ decreased the volume by 2mL each time and kept the pressure data for every 2mL

3. We took the data up to ~~14mL f~~ 14mL from the Zero point at 20mL, then took the zero point data once again to verify that no air left the system.

4. We repeated this process 3 times to verify the validity of the data.

Raw Data 1: Procedure for Boyle's Law

September 11, 2018 [redacted]

Charles' Law Observations

	Trial #1	trial #2
V_1 (mL)	148 mL	148 mL
T_1 (°C)	68.8°C	92.7°C
V_2 (mL)	95.1 mL	110 mL
T_2 (°C)	5.8°C	5.2°C
V_{cw} (mL)	52.9 mL	38 mL

- Once Erlenmeyer was placed upside down and finger was released, water rushed in

V_1 = Volume of gas in flask at start
T_1 = Temperature of gas after in boiling water ~~for~~ 6-7 mins
V_2 = Volume of gas after ~~placed~~ placed in ice bath for 6-7 mins
T_2 = Temp of ice bath

- First test did not measure temperature long enough

Raw Data 2: Observations for Charles' Law

September 11, 2018 [redacted]

Boyle's Law Observations

Trial 1:

Volume (mL)	Pressure (kPa)
0	102.36
2	114.03
4	127.74
6	145.70
8	167.57
10	200.18
12	226.01
14	226.01

Trial 2:

Volume (mL)	Pressure (kPa)
0	102.36
2	113.58
4	126.94
6	144.92
8	~~199.~~ 169.01
10	200.20
12	226.03
14	226.03

Trial 3:

Volume (mL)	Pressure (kPa)
0	102.21
2	114.86
4	128.75
6	146.02
8	169.60
10	199.38
12	226.04
14	226.04

* Pressure levels out at 14mL

Raw Data 3: Observations for Boyle's Law

Citations

1) Cohen, I. B. (1964). Newton, Hooke and 'Boyles Law' (Discovered by Power and Towneley). *Nature,204*(4959), 618-621. doi:10.1038/204618a0
2) Hall, N. (2015, May 05). Boyle's Law. Retrieved September 18, 2018, from https://www.grc.nasa.gov/www/k-12/airplane/boyle.html
3) Olmsted, J., Burk, R. C., & Williams, G. M. (2016). *Chemistry* (12th ed.). Toronto, ON: John Wiley & Sons Canada.
4) What is Charles' law? (n.d.). Retrieved September 18, 2018, from https://www.scientificamerican.com/article/what-is-charles-law/