<u>Lab #1: Verification of Charles' Law and Boyle's Law</u>

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Submitted To:

CHM1311

Theory

Gases are one of the 4 states of matter in the universe. Gas is extremely important to human life as it provides oxygen to the lungs and it allows the excretion of Carbon Dioxide. They are characterized as having large separation between particles, therefore they have variable shapes and volumes. Because of this, the physical properties of a gas can change by variation in volume, temperature and pressure.

An ideal gas in theory, has particles that undergo perfectly inelastic collisions and do not take up any volume. An ideal gas can be modeled using the equation: pV = nRT. In a practical sense, gasses do take up volume and do not undergo perfectly inelastic collisions occur. Therefore properties for the ideal gas are only met in situations of high temperature and low pressure. When the temperatures lower and the pressure increases the ideal gas properties are not met. Both of the experiments performed assume that the air used is an ideal gas.

Charles' Law

Charles' Law is one of the ideal gases laws which model the relationship of the volume and temperature of a gas. The equation being: $\frac{V1}{T1} = \frac{V2}{T2}$. According the Charles's Law the volume and temperature of gas are directly proportional. As the temperature of the gas increases the volume of the gas expands and as the gas cools the volume contracts. This principle however can only occur if the pressure of the gas is constant. Since the temperature is the average kinetic energy of the gas, the speed and number of collisions the particles undergo are directly affected by this. If the temperature rises the particles will collide with more speed and more frequently causing them to spread out. If the temperature drops the particles will collide with less speed and less frequently causing them to come closer to each other. If the pressure is not constant then the particles could have the same volume despite a temperature change. Therefore, it is important to maintain a constant pressure in the experiment.

Boyle's Law

Boyle's law is a law about ideal gases, which in definition, means a gas that has no specific characteristics. This means the gas has to be considered to have no particle volume, there is no energy lost within collisions of particles during any reaction, the particles have no charge (neither attract or repel), and the particles have random movement. Ideal gases are used to make simple calculations so that smaller details which have little effect on the laboratory experiment are not considered. Boyle's law takes an ideal gas and explains that the volume is inversely proportional to the pressure, given that the gas maintains a constant temperature. This means that as the volume decreases, the pressure increases. This happens because due to the fact that there are more collisions of particles when the area is compressed, making the particles try and break out of the container, causing increase of pressure. It is important to maintain a constant temperature during the entirety of the experiment due to the fact that this can also manipulate the pressure in the case of thermal expansion. If the law were to be described in symbols, it would be :

$$P \propto \frac{1}{V}$$

or

$$PV = k$$

P means pressure, V means volume, and k is a constant, which is the product of P and V.

Given that $P_1V_1 = k$ and $P_2V_2 = k$, meaning that two values of P and V, when multiplied, from the same experiment are equal to the same constant, a conclusion can be pulled that $P_1V_1 = P_2V_2$ This means that the product of the first instance of recorded pressure and volume are equal to the product of a second instance of recorded pressure and volume. This can be used to find missing variables if ever needed by using simple algebra to isolate.

Materials and Methods:

Materials:

For a list of the materials refer to the Experiment 1 Theory and Instructions lab handout pg 6.

Experimental Procedure for Charles' Law:

Refer to the Experiment 1 Theory and Instructions lab handout pgs 7-8.

Experimental Procedure for Boyle's Law:

1. Attach the pressure sensor to Labquest 2 and make a new file.
2. Move the plunger of the syringe to 18 ml. The base of the triangular tip of the syringe is the marker.
3. Attach the syringe to the pressure sensor.
4. Apply a half turn to the syringe to lock it in place.
5. Set the mode on the LQ2 to events with entry.
6. Set name of volume variable to Volume(mL), and the pressure variable to Pressure(kPa).
7. Set units to mL and kPa respectively.
8. Hold the plunger at desired volume and once pressure indicator is stabilized, record entry.
9. Move the plunger in 2mL interval in the sensor direction (lower volume).
10. Repeat step 8-9 a total of 5 times.
11. Move plunger back to original position(18mL) and record data entry.
12. Remove one of the original data points in the LQ2.
13. Tap analyze once all the points are set and choose desired curve fit.
14. Click fit equation and choose 1/x
15. Record all data in the hardcover chemistry notebook.
16. Extract all LQ2 data onto USB.

Observations and Data Analysis:

Charles' Law:

Trial #	Initial Water temperature	Air Temp inside flask	Initial Ice Bath Temp	Final Ice Bath Temp	Volume inside Graduated Cylinder	Volume of water up to the stopper
a	373.15 K	373.15 K	278.15 K	278.15 K	34 ml	151 ml
b	373.15 K	373.15 K	278.15 K	280.55 K	45.5 ml	151 ml

1. Volume Temperature Pair for V1 and T1:
   $V1_a = 151ml,\ V1_b = 151ml,\ T1_a = 278.15\ K,\ T1_b = 280.55\ K$
2. Calculation of V2:
   a. $V2 = V1 - V_{cw} = 151\ ml - 34\ ml = 117\ ml$
   b. $V2 = V1 - V_{cw} = 151\ ml - 45.5\ ml = 105.5\ ml$
3. Verification of Charles' Law:

$$\frac{V1}{T1} = \frac{V2}{T2} \rightarrow \frac{V1}{T1} - \frac{V2}{T2} = 0$$

   a. $\frac{151\ ml}{373.15\ K} - \frac{117\ ml}{278.15\ K} = -0.0159$
   b. $\frac{151\ ml}{373.15\ K} - \frac{105.5\ ml}{280.55\ K} = 0.0286$

Theoretically the values calculated should equal 0. However due to potential measurement and human error during the experiment and due to the fact that the air in the experiment was not a perfect ideal gas, the values do not equal 0.

4. Average Value: $(-0.0159 + 0.0286)/2 = 0.00635$

5. Percent Error:

   Percent error $= \frac{\frac{V1}{T1} - \frac{V2}{T2}}{\frac{V1}{T1}} \times 100\%$

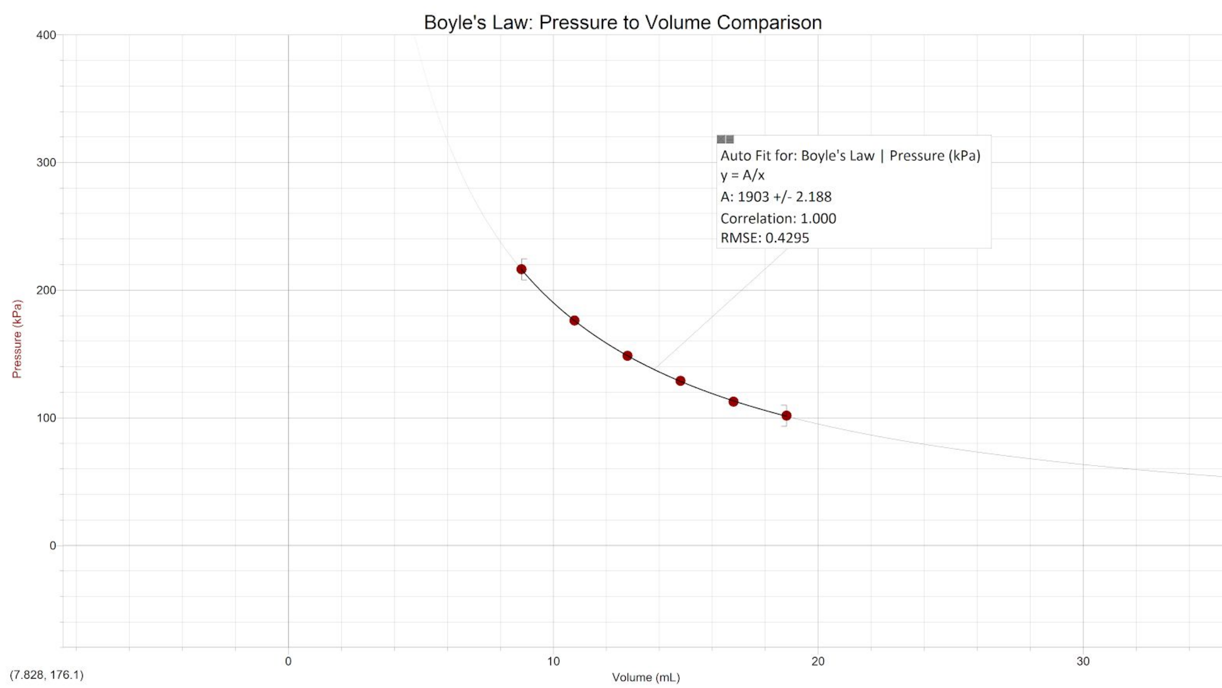
   a. $\frac{-0.0159}{\frac{151}{373.15}} \times 100\% = -3.93\%$
   b. $\frac{0.0286}{\frac{151}{373.15}} \times 100\% = 7.06\%$
   c. Percent error of average value: $\frac{0.00635}{\frac{151}{373.15}} \times 100\% = 1.57\%$

Boyle's Law:

Volume (mL)	**Pressure (kPa)**
18.8	101.69
16.8	112.54
14.8	128.91
12.8	148.44
10.8	176.10
8.8	216.30

1. Calculations of each respective k value:
    a. $18.8 * 101.69 = 1,911.772$
    b. $16.8 * 112.54 = 1,890.672$
    c. $14.8 * 128.91 = 1,907.868$
    d. $12.8 * 148.44 = 1,900.032$
    e. $10.8 * 176.10 = 1,901.88$
    f. $08.8 * 216.30 = 1,903.44$
        i. The constants were each calculated by using the $P_1 * V_1 = k$. Now to calculate a Boyle's law average constant, or k_{avg}, the average of all the constant values is calculated: $(1,911.772 + 1,890.672 + 1,907.868 + 1,900.032 + 1,901.88 + 1,903.44$)/6=**1,902.61 = k.** This is used as the final experimental constant.
2. The mathematical relationship illustrated by Boyle's law is that the pressure of the gas is inversely proportional to its volume. This means that when the volume and pressure are multiplied, they equate to a constant, *k*, which is called the Boyle's law constant. For this specific experiment, *k* is equal to 1,902.61, on average. Theoretically, the constant should be the same throughout all the changes of volume recorded in the experiment, but since there is experimental human error, such as inaccurate syringe movement and calculations based on the lines, there is inaccurate calculations, which causes a difference in the constants. The largest margin was 21.1 kPa between the first and second values recorded. This means that from the first data entry, there was a human error percentage of 1.1%. Theoretically, all *k* values have to remain the same, meaning *k=k*. *K* is calculated through the *PV* equation, and since *k=k*, P_1V_1 equates to P_2v_2. This is where it can be concluded that $P_1V_1 = P_2V_2$. The pressure multiplied by the volume of every single data entry gives the same theoretical result, meaning that they all equal to each other.

3. The importance of taking multiple readings of the dependent variable for the same value of the independent variable is important because this can aid in easily identifying human and calculation error during the experiment. This can also indicate environmental changes since the start of the experiment to help with identifying if there was a significant change outside of the experimental environment affecting the results. If the results for the independent variable are the same, then a conclusion can be pulled that no human error has botched the experiment.
4. The other variables that Boyle's law require to be met are temperature and moles of the gas. To ensure that the temperature stayed constant, the syringe was not touched with hands or any part of the body that could be used to heat it up from the regular original room temperature. Had this happened, the gas could have expanded inside the syringe, causing a higher pressure and modifying the results of the experiment. Although the changes would be very slim, they would still exist, and cause inaccuracy in the overall results of the experiment. To ensure that the moles of the gas did not change, it was ensured that the syringe was fastened tightly onto the pressure sensor. Had the gas escaped, this would have changed the volume of the gas, making the pressure go down. This would have required an entire re-do of the experiment. This did not happen as proper precautions were taken.



	Boyle's Law	
	x	y
1	18.8	101.69
2	16.8	112.54
3	14.8	128.91
4	12.8	148.44
5	10.8	176.1
6	8.8	216.3

Discussion

The purpose of this experiment was to verify Charles' Law and Boyle's Law. In order to verify Charles' Law, temperature was manipulated in order to observe the volume of gas in a 125 ml erlenmeyer flask. The gas inside the erlenmeyer flask was heated to 373.15 K and was submerged in an ice bath and the hole in the stopper was opened allowing the water to rush in. Once the temperature was equalized, the temperature of the ice bath was recorded and the volume of water inside of the beaker was recorded. The total volume of the beaker was subtracted by the volume of water in the ice bath to retrieve the volume of the gas in the second temperature (equilibrated temperature of ice bath). The volume of gas in the initial temperature (373.15 K) corresponds to the total volume of the beaker (until the bottom of the stopper). 2 trials were performed for greater scientific accuracy.

The data obtained from the experiments was used to verify Charles' Law using the equation: $\frac{V1}{T1} - \frac{V2}{T2} = 0$. Theoretically, the data used in the Charles' Law equation should produce 0. This is because the volume and the temperature of a gas are directly proportional. As the gas heats, the volume of the gas expands. As the gas cools the volume of the gas contracts. However, since no real gas is a perfect ideal gas, an answer of 0 is extremely unlikely. The first trial produced a result of: -0.0159 and the second trial produced a result of: 0.0286. Both the answers are close to 0 and are within the same order of magnitude however the second trial produced a result that is more inaccurate to verifying Charles' Law. When calculating an average value over both the trials, the answer obtained was 0.00635 which is much closer to the desired result. A percent error calculation was conducted to further verify Charles' Law. The first trial produced a percent error of: -3.93% and the second trial produced: 7.06%. Finally the average value produced a percent error of: 1.57%.

All of the data produced a percent error less than $\pm 8\%$ with the average value producing a percent error less than 2%. However multiple trials were conducted to increase the overall accuracy of the experiment. Since the calculations obtained results close to 0 and the percent errors were less than 10%, the results of the experiment support the verification of Charles' Law.

The results of the second trial indicated some errors. These errors included measurement and human error. The measurement error could have occured when using the thermometer to measure the ice bath. Areas closer to the heated beaker were warmer then areas farther from the beaker in the ice bath. A source of human error could have been inaccurately measuring the water level when the beaker was under water. Another source of human error was getting an incorrect reading on the graduated cylinder. These sources of error skewed the results slightly, especially the second result. However despite this the results still support the verification of Charles' Law.

In order to verify Boyle's law, an independent variable, the volume of a gas(air) was manipulated inside of a closed environment (syringe) to modify the dependent variable, the pressure of the gas. The syringe was first filled fully with air, and then brought down to 18.8mL of air, to create an initial data entry point so that the pressure would be manipulated in order to create the first constant value with the use of Boyle's law. This may be called the "master" dependent value, as it was used to compare all the human error and differences found during calculation. The master value was later re-recorded for greater scientific accuracy. Due to the fact that the values were very similar, with less than a 0.1% change in between the both, it was decided that the second recording of the dependant variable was crossed out and not used. Outside temperature was not recorded due to the fact that the result manipulation in the case of temperature change would be so miniscule that they would go unnoticed in comparison of human error. The laboratory equipment was not possibly accurate enough to include the outside temperature as a changing factor.

The data produced from the experiment was used to verify the integrity of Boyle's law in the following equation: $P_1V_1 = P_2V_2$. In theory, each product of the dependant and independent variable should produce the same result, which would mean that *k=k*. This is due to the fact that the pressure and volume of an ideal gas are inversely proportional. However, once again, air is not an ideal gas. An ideal gas is simply a theoretical concept. Even so, the largest difference in independent variables is 21.1kPa, which equates to a total of 1.1%. Human error is a common occurrence, particularly in cases where human movement is involved. This was the largest human error percentage recorded in the entire experiment. All of the results, when averaged, equated to 1,902.61. The largest difference of a result to the average is 11.938kPa, which is a difference of 0.63%.

All of the data produced a percentage error of 1.1% max difference and 0.63% difference from the average. This is very much in the acceptable range for human error. Since this is the case, it is possible to confirm the integrity of Boyle's law based on experimental calculations. All of the percentages were well under the maximum of 10%.

There were a few possibilities of human error that could have affected the results of the experiment. One major error was the fact that a human hand was used to move the syringe to the proper positions. Since there is no way to accurately calculate the exact volume that the syringe plunger was moved to, everything had to be done through estimation when looking at how close the plunger was to the line. Had the plunger been even a portion of a millimeter off, the results could change. Because the plunger was gradually more difficult to push down since the pressure increased exponentially, accurate results became more and more difficult to record. Since there was no machine to hold the syringe down, the plunger fluctuated in a sinusoidal manner when trying to manually balance the plunger on the line, where human force had to combat the opposing pressure of the air forcing it up. However, despite this, the percentage of human error was so miniscule that the integrity of Boyle's law could still be confirmed and verified.

Conclusion

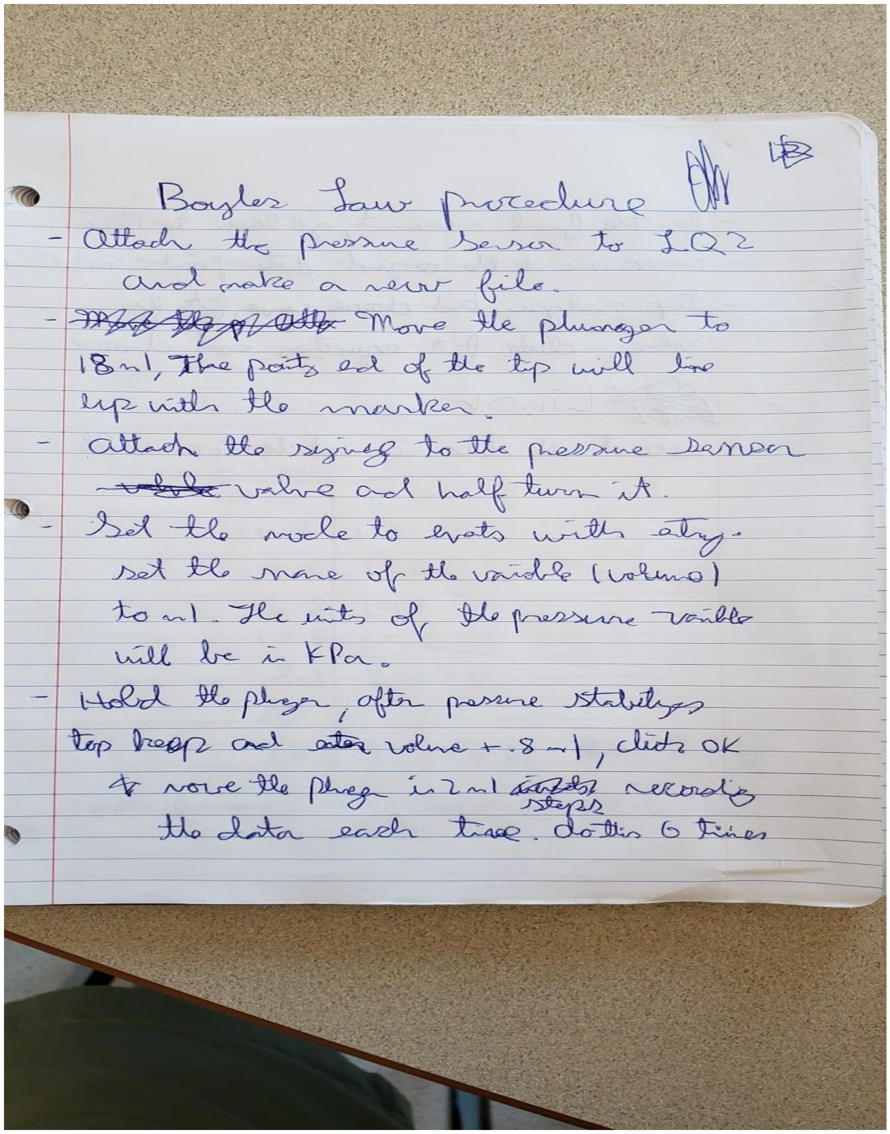
In conclusion both the experiments supported the verification of Charles' Law and Boyle's Law respectively. The results from the Charle's Law experiment were found to have a value of 0.00635 with a percentage error of 1.57%. This supports the verification of Charles' Law as the equation in theory produces a value of 0 and the results produce a value close to 0 with little error. This supports that the volume and temperature of a gas are directly proportional to each other. The results from the Boyle's law experiment were found to have a maximal margin of 21.1kPa and averaged fairly closely together to form a very similar Boyle's constant. This gave a maximal percentage error of only 1.1%. This supports the verification of the Boyle's Law as the constants were very similar and recorded so closely together. Since the constants could be considered equal, the fact that the product of one instance of the pressure and volume are equal to the product of a second instance of the pressure and volume when recorded in the same environment. This verifies Boyle's Law.

Works Cited

1. Chieh, Chung. “The Ideal Gas Law.” *Chemical Reaction Equations*, University of Waterloo, 12 Aug. 2016, www.science.uwaterloo.ca/~cchieh/cact/c120/idealgas.html.
2. Leon, N De. “Charles Law.” *Rutherford Model of the Atom*, Indiana University, 20 Mar. 2015, www.iun.edu/~cpanhd/C101webnotes/gases/charleslaw.html.
3. NASA. “Boyle's Law.” *National Aeronautics and Space Administration*, NASA, 5 May 2015, www.grc.nasa.gov/www/k-12/airplane/boyle.html.

Appendix:

Documentation of Raw Data



Boyles Law procedure

- Attach the pressure sensor to LQ2 and make a new file.
- Move the plunger to 18ml, The pointy end of the tip will line up with the marker.
- Attach the syringe to the pressure sensor valve and half turn it.
- Set the mode to events with entry. set the name of the variable (volume) to ml. The units of the pressure variable will be in KPa.
- Hold the plunger, after pressure stabilizes tap keep and enter volume +.8 ml, click OK & move the plunger in 2 ml steps recording the data each time. do this 6 times

Data

Trial 1 a)	Trial 2 a)
Ice $temp_{initial}$ 5.1°C	Ice temp 5.1°C
Ice temp 5.0°C	Ice temp 7.3°C
~~[illegible]~~ V_{cw} = 34 ml	V_{cw} = 45.5 ml
V_1 = 151 ml	V_1 = 151 ml

b)

Vol (ml)	KPa
18.8	101.69
16.8	112.54
14.8	128.91
12.8	148.44
10.8	176.10
8.8	216.30
~~[illegible]~~	
18.8	101.67 ~~[illegible]~~

note pressure sensor caps @ 226.60 KPa

- for the final measurement, go back to 18 ml.
- remove one of the original data points in LQ2
- tap analyze and choose curve fit for value, click fit equation and choose ~~[illegible]~~ Linear
- record all data in notebook as well

Verification of Gas Laws

Sept 11 2018

~~DAtat~~ -> wow

Data

Charles

Inital water temp: 100°C (Boiling) -> Max water temp
Air inside flask: ~100°C -> in boiling water

1st:
Ice bather temp: 5.0°C -> inital
Ice bath temp: 5.0°C -> final
Volume inside grad cylinder: 34 ml -> 1st try

2nd:
Ice bath temp: 5.0°C -> initial
Ice bath temp: 7.4°C -> Final
Volume inside grad. cylinder: 45.5 ml

Boyle

-> V_1: 151 mL

Volume (Ml)	Pressure kPa
18 mL	101.69
16 mL	112.54
14 mL	128.91
12 mL	148.~~51~~44
10 mL	176.10
8 mL	216.30
18 mL v2	101.67

Note: add 0.8 to all mL values

Note: pressure meter caps at 226.60 kPa making further research impossible to record past the 8 mL mark

Using first due to reduced unscrewing/release of air and less human error

Chem Lab 9 / 11 /

Attach Pressure sensor → LQ2
Move plunger to 18 ml → pointy end
Attach syringe to pressure sensor
Half turn value
Set mode to events with entry
Set name of volume variable
to ml. units of pressure will be
in kPa.
Hold the plunger and after pressure
stabilizes, tap keep and enter volume
18ml, click OK ~~and~~.
Move plunger in 2ml intervals while
recording the data each time.
Do this 6 times
on the 7th time move plunger
back to 18 ml. Record again
Remove one of the original data
points in LQ2.
Tap analyse and choose curve fit
for volume,
Click fit equation and choose $\frac{1}{x}$
Record all data in note book
Extract LQ2 data from USB

Charles Law

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Boyle's Law

$$P_1 V_1 = P_2 V_2$$

$$\frac{V_{TOTAL}}{273 + 100k} = \frac{V_{TOTAL} - V_{COLD}}{273 + 5.0}$$