Verification of Gas Laws

CHM1311 - Z01

Date: September 18th, 2018

Introduction

The purpose of this lab was to verify both Charles' Law and Boyle's Law. Both of these gas laws deal with ideal gases. Ideal gases are assumed to have molecules that do not attract one another, have no energy losses and occupy a negligible volume. However, no real gas is ideal. Real gases only follow these predictions within ±5% at both normal temperatures and pressures, not temperatures that are close to absolute zero or pressures that are too high (depends on the gas itself) ("Gases").

Charles' Law states that volume and absolute temperature (K) are directly proportional when pressure is constant (Tenny & Cooper, 2018). As the temperature of a gas increases or decreases, the volume of said gas will expand or contract, respectively (Silberberg, Amateis, Lavieri, & Venkateswaran, 2016).

A limitation of Charles' Law occurs when the temperature is close to absolute zero. At such a low temperature, the gas will condense into a liquid. This means that Charles' Law cannot be used at very low temperatures, as a gas' volume will never be 0mL (Venkateswaran, 2018).

Charles' Law is written as:

$\boldsymbol{V = kT}$, *where:*
V = gas' volume at a constant pressure, mL
T = the absolute temperature, K
k = constant term

To verify Charles Law, one would use the equation:

$\frac{V_1}{T_1} = \frac{V_2}{T_2}$, *where:*
V_1 *= initial volume of a gas, mL (volume of Erlenmeyer flask to the bottom of the stopper)*
V_2 *= final volume of a gas, mL (*$V_2 = V_1 - V_{CW}$*)*
T_1 *= initial temperature of a gas, K (temperature of air in the boiling water)*
T_2 *=final temperature of a gas, K (temperature of the air in the ice water bath)*

If Charles' Law was obeyed, this equation would hold true and the left side would be equal to the right side. The data measured in the Charles' Law experiment is both temperature and volume, as Charles' Law describes how gases expand as they are heated when pressure is constant.

Boyle's Law states that the pressure and volume of a gas are inversely proportional when temperature is constant (Tenny & Cooper, 2018). When the volume of a gas decreases, molecules have less space to move, thus increasing collisions and pressure, whereas when the volume of a gas increases, molecules have more space to move, decreasing the number of collisions and pressure (Silberberg et al., 2016).

Boyle's Law cannot be applied when a gas reaches a high pressure, as said gas will become a solid or liquid. This is a limitation of the law ("Gases").

Boyle's Law is written as:

$\boldsymbol{PV = k}$, *where:*
P = gas pressure, kPa
V = gas volume, mL
k = constant term

To verify Boyle's Law, one would use the equation:

$\boldsymbol{P_1V_1 = P_2V_2}$, *where:*
P = pressure of a gas, kPa
V = volume of a gas, mL

If Boyle's Law was obeyed, this equation would hold true and the left side would be equal to the right side. The data measured in the Boyle's Law experiment was both pressure and volume due to the fact that Boyle's law states that they are inversely proportional when temperature is constant.

Procedure

Charles' Law
As described in the lab manual (Verification of Gas Laws, Dr. Rashmi Venkateswaran, 2018, Exp, 1, pgs. 7-8).

Boyle's Law

1. Goggles and lab coat were worn at all times in the laboratory.
2. A 20mL syringe and a gas pressure sensor were obtained.
3. The syringe plunger was moved to the 10mL marking and attached to the gas pressure sensor, being careful not to overtighten.
4. The gas pressure sensor was connected to LabQuest 2 (LabQuest 2 instructions are detailed in the lab manual (Verification of Gas Laws, Dr. Rashmi Venkateswaran, 2018, Exp, 1, pgs. 8-10).
5. The plunger was held at 10mL. Once the pressure was stabilized, the volume and pressure were recorded in LabQuest 2 and a table, adding a 0.8 volume surplus due to the space inside the sensor.
6. Step 4 was repeated for volumes 7-13mL, recording all results in LabQuest2 and a table, repeating the 10mL measurement again as the final measurement.

Data and Observations

Table 1: Charles' Law Quantitative Observations

	Trial 1	**Trial 2**
T_1 (K)	373.15	373.15
T_2 (K)	277.85	278.05
V_{CW} (mL)	25.9	29.9
V_1 (mL)	154.2	148.8

Table 2: Boyle's Law Quantitative Observations

Volume (mL)	**Pressure (kPa)**
7.8	140.52
8.8	124.70
9.8	112.72
10.8	102.15
11.8	94.25
12.8	86.02
13.8	81.19

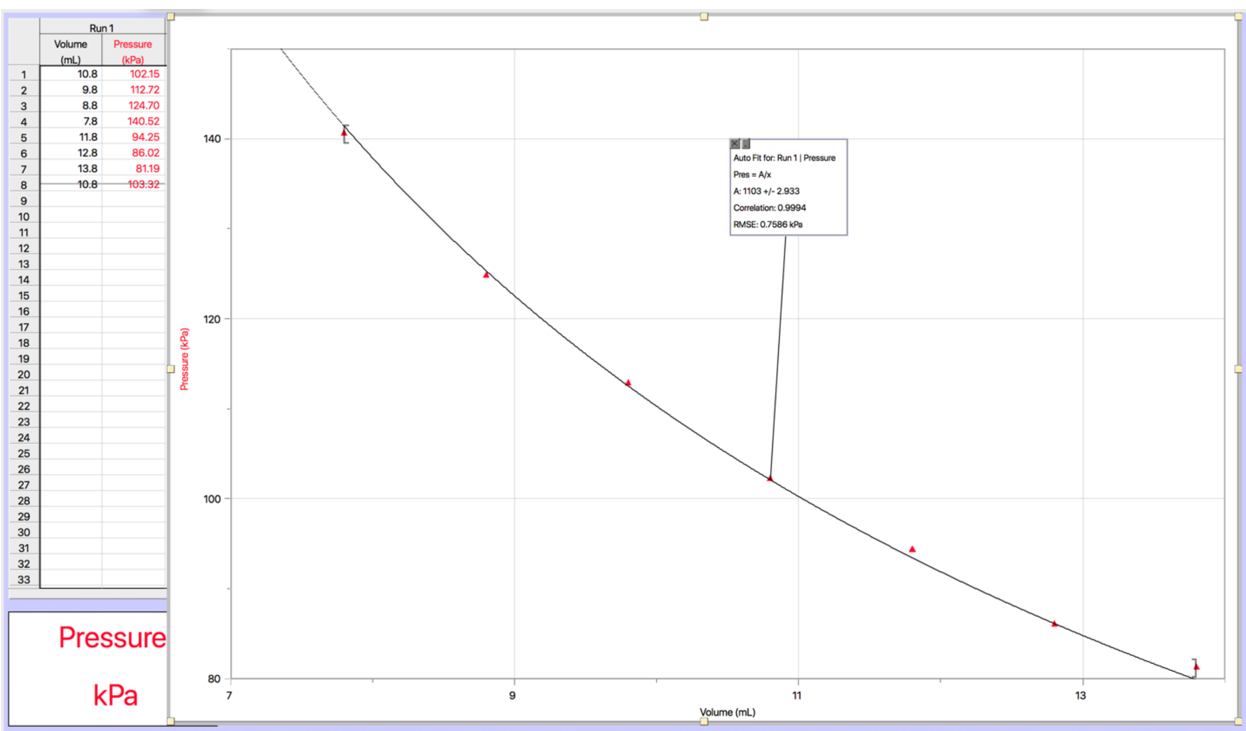

Figure 1: The Pressure of Gas (kPa) as a Function of Volume (mL)

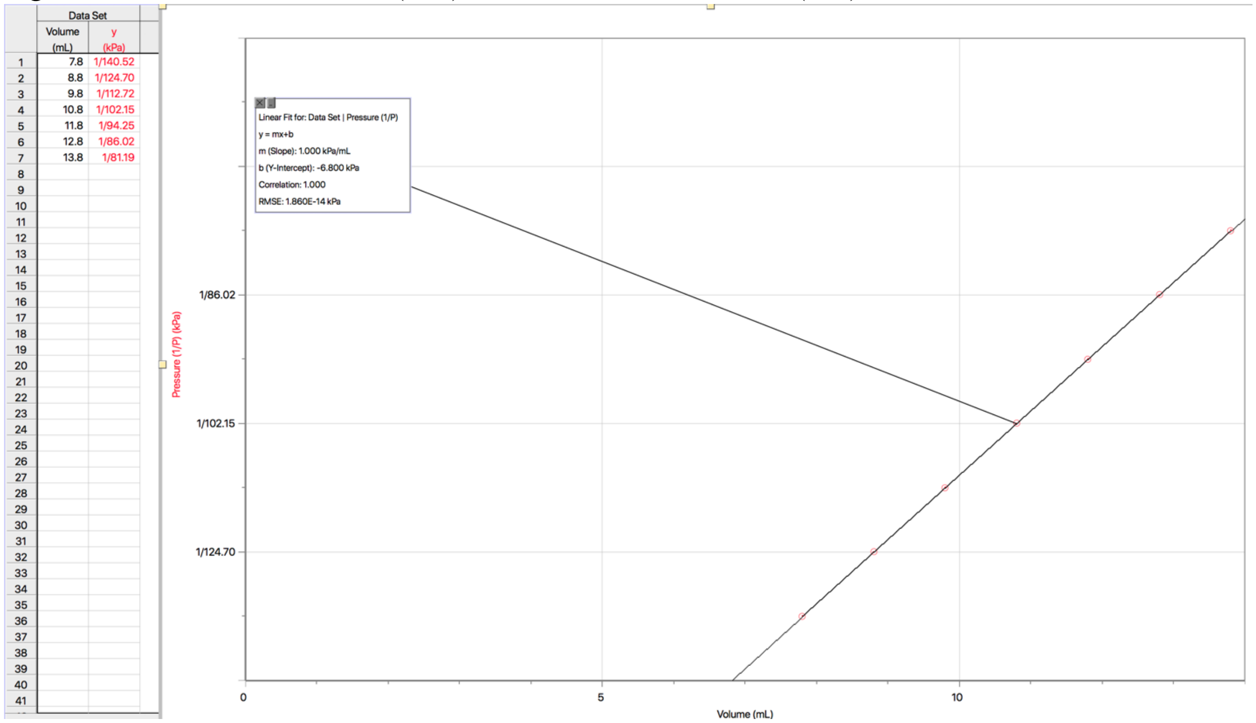

Figure 2: 1/Pressure of Gas (kPa) as a Function of Volume (mL)

Observations: An observation made for Charles' Law was that there was water that remained in the Erlenmeyer and graduated cylinders when measuring V_1 and V_{Cw} (further discussed in discussion).

One observation made during the Boyle's Law experiment was that it was difficult to push the syringe past 7mL, and we had to change our volumes accordingly (from 4-9mL to 7-13mL).

Calculations

Charles' Law

$V_1 = 154.2$, $T_1 = 373.15$ K

V_2

$$V_2 = V_1 - V_{CW}$$
$$V_2 = 154.9mL - 25.9mL$$
$$V_2 = 128\ mL$$

Verify Charles' Law

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

$$\frac{154.2mL}{373.15K} = \frac{128.3mL}{277.85K}$$

0.4132mL/K = 0.4618mL/K
0.4132mL/K≠0.4618mL/K

Average Value

$$\frac{\frac{V_1}{T_1} Trial\ 1 + \frac{V_1}{T_1} Trial\ 2}{2} = \frac{\frac{V_2}{T_2} Trial\ 1 + \frac{V_2}{T_2} Trial\ 2}{2}$$

$$\frac{\frac{0.4132ml}{K} + 0.3988mL/K}{2} = \frac{\frac{0.4618mL}{K} + 0.4276mL/K}{2}$$

0.4060mL/K = 0.4447mL/K
0.4060mL/K≠0.4447mL/K

Percent Error

$$\%\ Error = \frac{\frac{V_1 - V_2}{T_1 - T_2}}{\frac{V_1}{T_1}}\ x\ 100\%$$

$$\%\ Error = \frac{\frac{154.5mL}{373.15K} - \frac{128.3mL}{277.95K}}{\frac{154.5mL}{373.15K}}\ x\ 100\%$$

% Error = -11.76%

Boyle's Law

Boyle's Law Constant

Boyle's Law states that pressure and volume are inversely proportional. A constant (k) can be calculated by multiplying both a value for pressure (P) and a value for volume (V).

$PV = k$
$(10.8)(102.15) = 1.10x10^3$

Boyle's Law Equation with Constant

$P_1V_1 = k$
$P_1V_1 = 1.10 \times 10^3$

$P_2V_2 = k$
$P_2V_2 = 1.10x10^3$

$P_1V_1 = k$
$P_2V_2 = k$
$P_1V_1 = P_2V_2$

<u>**Discussion**</u>

Charles' Law

The results demonstrated that gases do expand when heated and condense when cooled. The relationship of Charles' Law was verified, as it was found that the volume and temperature of the gas were proportional when pressure was held constant. However, the numerical values were not equal, as $\frac{V_1}{T_1} \neq \frac{V_2}{T_2}$, so the law was unable to be verified quantitatively. This was to be expected, as it would be very difficult to perform this lab and find ratios that were exactly equal due to the multiple sources of error.

The second trial had ratios that were closer to being equal in comparison to the first trial (Second trial: $\frac{V_1}{T_1}$ = 0.3988mL/K and $\frac{V_2}{T_2}$ = 0.4276mL/K, first trial shown in calculations). This may be due to the fact that one trial had been completed previously, thus making us more comfortable with the experiment, lowering the chance for human error.

Experimental shortcomings include the experiment being performed in an open system. Due to this, there was potential for a loss of heat. This would affect the accuracy of the value for T_1. If the true temperature value was cooler than the one recorded, the $\frac{V_1}{T_1}$ ratio would have been higher, making it closer to the $\frac{V_2}{T_2}$ ratio, and lowering the percent error. Another error was the measurement of V_1. When measuring V_1, multiple graduated cylinders were used as there was not one large enough to measure the total volume of the water. In doing so, there was possibility for lost water when transferring the water to the graduated cylinders. This would have affected the data by lowering the volume found, thus affecting the accuracy of the ratios. If no water would have been lost, the $\frac{V_1}{T_1}$ ratio would have been higher, making it closer to the $\frac{V_2}{T_2}$ ratio and lowering the percent error.

A theoretical shortcoming of Charles' Law is that is unable to be used at temperatures close to absolute zero, as a gas' volume can never be 0mL (the gas will condense into a liquid at such a low temperature). However, this shortcoming was not encountered during the experiment, due to the fact that the experiment did not deal with such low temperatures.

Boyle's Law

The results demonstrate that the volume and pressure of a gas are indeed inversely proportional. Boyle's Law was also verified, as the results did demonstrate that when temperature is constant, the volume and pressure of a gas are inversely related.

I believe multiple readings of the dependant variable for the same value of the independent variable were taken as it allows for a more accurate reading. Taking the reading at 10.8mL twice allowed us to choose which of the two points followed the curve of the graph more closely. Multiple readings also allow for the average of the readings to be found.

Boyle's Law requires that the temperature be constant, a theoretical shortcoming. This was something that was taken into consideration, however, it was simply assumed that the temperature in the room would remain constant. Since the Charles' Law experiment was also being conducted at the same time, the room temperature most likely did not remain constant due to the use of hot plates around the laboratory. This would in turn affect the results, as an increase in temperature would affect the volume of the gas directly, as seen in the Charles' Law experiment. An increase in the temperature of the room may have caused the gas to expand. An increase in temperature would also add another variable into the equation, thus creating the combined gas law, but since no temperature was measured, this could not be calculated.

Experimental shortcomings include the reading syringe. It would be nearly impossible to hold the syringe at the exact volume. This would have affected the volumes, as they may not have been the exact recorded values. This would in turn affect the pressures as the pressure recorded on LabQuest2 may have been for a volume different than what was recorded (ex: 10.5mL vs 10.8mL). This would have also lowered the constant found. Another source of error was the instability of the pressure. Though the pressure did somewhat stabilize, it constantly went back and forth between numbers, often a range of 0.5. Though the number is small, this may still have affected the results by either recording a pressure that was slightly higher or lower than the exact pressure, which would as a result raise or lower the constant, respectively . In order to improve the accuracy of this experiment and the results, more trials could have been performed and the average of the performed trials could have been used as well.

Conclusion

The relationship stated in Charles' Law was verified, as volume and temperature were found to be proportional when pressure is held constant. However, the numerical values exhibited a percent error of -11.76% and Charles' Law was not verified numerically. Boyle's Law was also verified, as the experiment showed that when temperature is constant, pressure and volume are inversely proportional.

References

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