Validation of Charles' and Boyle's Gas Laws

Authors:

Submitting Author's Partner:

Professor: St.Amant

Date Experiment Performed: 11/09/2019

Date Experiment Submitted: 18/09/2019

Procedure:

As outlined in the lab manual ("What in the World ISN'T Chemistry", General Chemistry Laboratory Manual, Dr. Rashmi Venkateswaran, 2019.)

Discussion:

Charles' Law

Charles law defines the relationship of direct proportionality between volume and temperature (in Kelvin) that takes place at a fixed number of moles and pressure. As temperature increases, an increased movement in gas molecules results in the expansion of gas and in turn, a linear increase in volume as seen by the mathematical representation:

$$k=V/T \text{ or } \frac{V1}{T1} = \frac{V2}{T2}$$

The results obtained in this lab are in agreement with Charles' Gas Law. According to *Table 1,* it can be seen that decreasing the temperature of the gas also decreases its volume. This consistency with the theoretical expectation of the experiment indicates that the procedure is fitting for this lab. For example, Trial #1 and #2 from Table 1 exhibit approximately equal values of k:

$$V1/T1=V2/T2$$

$$(147.5 \text{ mL}) / (373.0 \text{ K}) = (104.0 \text{ mL}) / (276.7 \text{ K})$$

$$(0.39544 \text{ mL/K}) \approx (0.37586 \text{ mL/K})$$

$$k_1 \approx k_2$$

A possible source of error is due to the covering of the rubber stopper hole with a finger while the Erlyenmeyer flask was being inverted into the ice bath. It is possible that moisture and impurities from the finger entered the Erlyenmeyer flask and affected its contents. This error has an effect on the results of the lab as it indicates that the volume of air which later condensed in the flask also contains additional moisture and impurities that were not originally present in the air sample. A way to minimize this error is by wearing disinfected rubber gloves when covering the hole of the rubber stopper. This ensures the flask's contents will remain pure while the experiment can still be carried out with a high degree of efficiency.

Another possible source of error is the inability to correctly equalize the pressure of the gas within the Erlenmeyer flask. An essential condition of Charles' Gas Law outlines that pressure levels must be constant across all trials. During the process of submerging the Erlenmeyer flask in the ice bath, it is possible that water levels were not matched precisely on both sides, creating a change in pressure, in which case Charles' Law no longer applies. In order to minimize the effect of this error, the inverting of the flask must be done in a clear, see-through plastic ice bath such that it would be easier to balance the level of the surrounding water with that of the Erlyenmeyer flask.

Boyle's Law

Throughout the experiment, it was observed that no matter what volume was chosen initially, the value of k remained relatively constant, averaging to 1988.74 mL•KPa across all trials. This consistency in results further validates our hypothesis and the basis of Boyle's law- The increase in pressure as a result of a decrease in volume is possible given that the amount of gas and the surrounding temperature conditions both remain constant [1].

Through thorough comparison of the results obtained for each of the six trials, it could be verified that as the volume of the air in the system decreased, the pressure increased in a nonlinear fashion. According to Figure 1, the graph of the pressure as a function of volume demonstrated an exponential decay curve. To further validate this, the pressure reading at a volume of 20.0 mL (102.37 KPa) was significantly lower than that obtained at a volume of 8.0 mL (226.19 KPa).

Possible sources of error include the systematic error of the syringe volume reading. While setting the volume at the desired value, the plunger of the syringe was seen to push back out due to the increased gas pressure inside the tube that resulted when surface area was decreased. The plunger had to be held firmly and steadily at the fixed volume mark. This limitation in the design of the procedure could have affected the results of this lab because the volume readings are not guaranteed to be as accurate as they could have been, as seen by the difficulty for the

---

[1] John B. West, *Journal of Applied Physiology*, 87(4), 1999, 1543-1545.

pressure in the syringe to stabilize. Replacing the syringe with a piston, whose tightly fitted disk is capable of compressing gas more effectively and at a fixed volume in a closed container, can significantly reduce the chance of imprecise volume readings.

A second possible source of error is the imprecision with regards to the added reading of 0.8 mL in each volume reading. Depending on the length of tubing connecting the syringe to the gas pressure sensor, there is the possibility that the 0.8 mL is imprecise. As there was no experimental testing performed to verify the internal volume of the gas pressure sensor, this added an uncertainty factor in all subsequent volume readings. Measuring the length of tubing along with the precise measurement of the internal volume of the gas pressure sensor prior to running the experiment will allow for more consistent data collection.

Taking multiple measurements of the dependent variable for the same value of the independent variable is important as it reduces the uncertainty range. In this experiment, the pressure was found to fluctuate by a certain degree between trials. Therefore, it is necessary to obtain multiple readings in order to ensure precision of the data results.

In order for Boyle's law to be validated, the number of moles of gas and the temperature of the gas must be kept constant. During the course of this lab procedure, these variables were taken into consideration by ensuring the syringe was securely locked to the sensor, reducing the chance of gas escape, and the experiment was performed in a uniform temperature environment, away from any heat sources. This is due to the fact that a change in temperature affects the results of the lab as seen by the following mathematical proof:

$$\frac{PV}{T} = q, \text{ where q is a constant.}$$

If the temperature of the air inside the syringe is increased while the volume is decreased, then the Gas Pressure Sensor will show a significantly higher value of pressure as compared to when the temperature had remained unchanged. In this case, both volume and temperature have an effect on pressure as per the combined gas law. A similar statement can be said for the change in the amount of gas: If the number of moles of air increases and the volume decreases, then there will be a significantly higher pressure reading since the air molecules will strike the walls of the syringe more frequently and with more force.

Conclusion:

In conclusion, the purpose of this lab was to validate Charles' and Boyle's Gas Laws through the manipulation of volume, pressure and temperature. The values obtained for Charles' Law were respectively 0.39544 mL/K for Trial #1 and 0.37586 mL/K for Trial #2 with a percent error of 4.952%. The values obtained for Boyle's constant averaged 1988.74 mL•KPa across all trials. The consistency of the k value for both Chalres' and Boyle's Laws indicate that the experimental procedures carried out were a success.

Reference(s):

"What in the World ISN'T Chemistry", General Chemistry Laboratory Manual, Dr. Rashmi Venkateswaran, 2019.

John B. West, *Journal of Applied Physiology*, 87(4), 1999, 1543-1545.

Appendix:

Additional Data, Charles' Law

Table 1: Experimental data of temperature of water bath, volume of air, and volume of Erlenmeyer flask.

Trial #	T_{water} (℃)	V_{air} (mL)	V_{flask} (mL)
1	4.3	28.9	148.1
2	3.7	43.5	147.5

Additional Graphs, Charles' Law

N/A

Sample Calculations, Charles' Law

The mathematical representation of Charles' Law can be obtained from the Ideal Gas Law,

$$PV=nRT$$

$$V = \frac{nRT}{P}$$

$$V = (\frac{nR}{P})T$$

Since the number of moles and the pressure of the gas must be kept constant, the expression can be rewritten as:

$V = kT$, where k is the proportionality constant.

$k = V/T$

If Charles' Law is obeyed, the values of volume and temperature must satisfy the following equation:

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

Calculations of Trail 2

T_1 = 100.0 °C + 273 = 373.0 K

V_1 = 147.5 mL

T_2 = 3.7 °C + 273 = 276.7 K

$V_2 = V_1 - V_{cw}$ = 147.5 mL - 43.5 mL = 104.0 mL

$\frac{V_1}{T_1} = \frac{147.5\ mL}{373.0\ K} \cong$ 0.39544 mL/K

$\frac{V_2}{T_2} = \frac{104.0\ mL}{276.7\ K} \cong$ 0.37586 mL/K

∵ LS ≅ RS

∴ QED

Since the ratios of the initial and final volume to temperature are approximately equal to each other, it can be said that Charles' Law has been verified.

Average Volume of Air

$$V_{air\ avg} = \frac{V_1 + V_2}{2} = \frac{28.9\ mL + 43.5\ mL}{2} = 36.2\ mL$$

Percent Error of Trial 2

% Error = ($\frac{V_1}{T_1}$ - $\frac{V_2}{T_2}$ / $\frac{V_1}{T_1}$) × 100%

= ($\frac{147.5\ mL}{373.0\ K}$ - $\frac{104.0\ mL}{276.7\ K}$ / $\frac{147.5\ mL}{373.0\ K}$) × 100%

≈ 4.952%

Table 2: Calculated values of volume to temperature ratios for validating Charles' Law.

Trial #	$\frac{V_1}{T_1}$ ratio (mL/K)	$\frac{V_2}{T_2}$ ratio (mL/K)
1	$\frac{148.1\ mL}{373.0\ K}$ ≅ 0.39705	$\frac{119.2\ mL}{277.3\ K}$ ≅ 0.42986
2	$\frac{147.5\ mL}{373.0\ K}$ ≅ 0.39544	$\frac{104.0\ mL}{276.7\ K}$ ≅ 0.37586

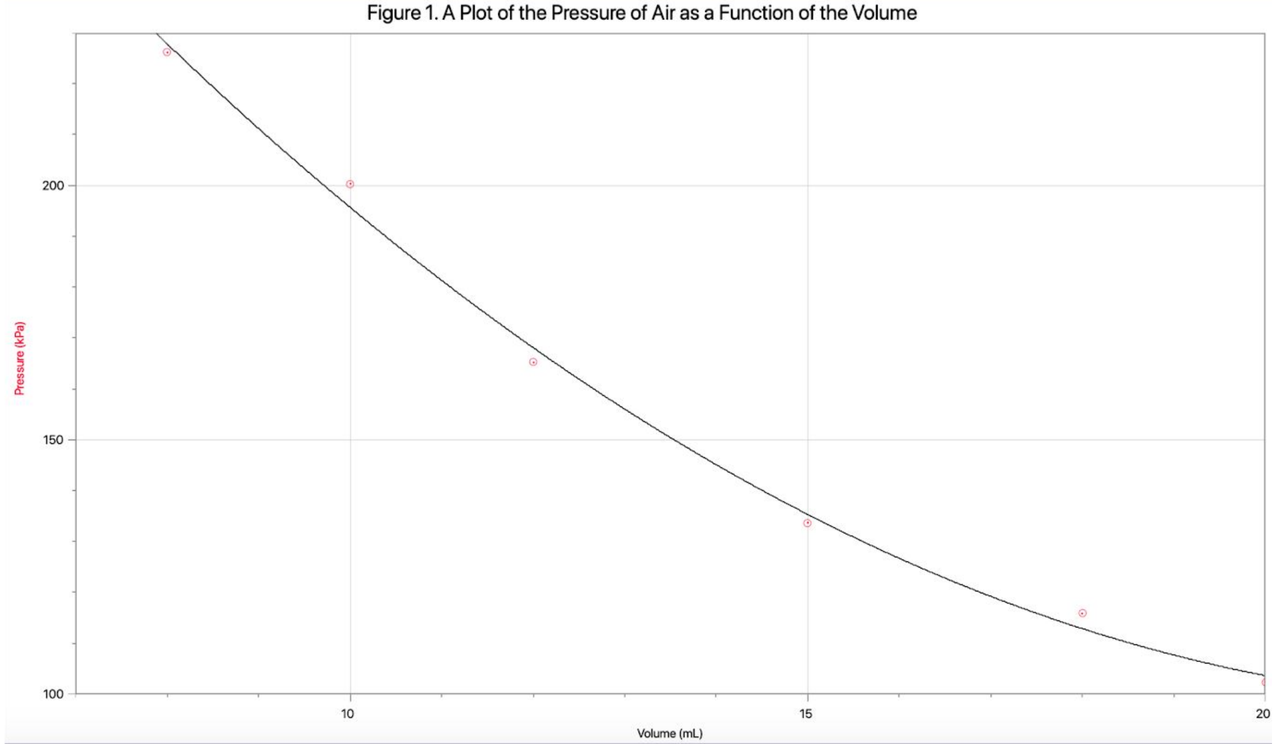
<u>Additional Data, Boyle's Law</u>

Table 3: Experimental values of the pressure of air recorded in the syringe-sensor system set at given volumes.

Trial #	V_{air} (mL)	P_{air} (kPa)
1	20.0	102.37
2	18.0	115.83
3	15.0	133.64
4	12.0	165.27
5	10.0	200.28
6	8.0	226.19

Additional Graphs, Boyle's Law

Figure 1. A Plot of the Pressure of Air as a Function of the Volume



Sample Calculations, Boyle's Law

Boyle's law can be defined as the inverse proportional relationship between pressure and volume. If the volume is decreased, then the pressure exerted on/by the gas will increase. Similarly, if the volume is increased, then the pressure exerted on/by the gas will decrease, given that all other conditions, namely temperature, remain *constant*.

[Pressure x Volume= Constant]

∴ PV=k

Calculating Boyle's constant Trial #1

When V=20.0 mL P=102.37 KPa

k=PV

k= [102.37 KPa] x [20.0 mL]

= 2047.4 mL•KPa

≈ 2050 mL•KPa

Calculating the average of Boyle's constant

$$K_{avg} = \frac{[(PV\ \#1)(PV\#2)(PV\#3)(PV\#4)(PV\#5)(PV\#6)]}{\#\ of Points}$$

$$= \frac{[(2047.4\ mL{\bullet}KPa)(2084.94\ mL{\bullet}KPa)(2004.6\ mL{\bullet}KPa)(1983.24\ mL{\bullet}KPa)(2002.8\ mL{\bullet}KPa)(1809.52\ mL{\bullet}KPa)]}{6}$$

= 1988.74 mL•KPa

Mathematical Relationship of Boyle's Law

As a result of the inversely proportional relationship that pressure and volume share, Boyle's law can be described by the relationship P=k/V or V=k/P, indicating that as pressure decreases, volume increases and vice versa. This succession of events is only possible if the number of moles and temperature of the gas remain constant (k constant). If these two conditions are met, the product of [V*P] will always equal a constant k, regardless of which data point is being accounted for.

P=k/V

k=PV

Thus, at any two different trial points, the constant must retain its value:

$P_1V_1 = P_2V_2$

As an example, Trial #3 and #5 from Table 3 seem to exhibit approximately equal values of k:

$$P_1V_1=P_2V_2$$

$$(101.57\ \text{KPa})\ (20.0\ \text{mL}) = (164.47\ \text{KPa})\ (12.0\ \text{mL})$$

$$(2004.6\ \text{mL}\bullet\text{KPa}) \approx (2002.8\ \text{mL}\bullet\text{KPa})$$

$$k_3 \approx k_5$$

Table 3: Calculated values of Boyle's constant using experimental data.

Trial #	k value (mL•KPa)
1	2047.4
2	2084.94
3	2004.6
4	1983.24
5	2002.8
6	1809.52