“Do I Dare Disturb The Universe?”

Verification of Gas Laws

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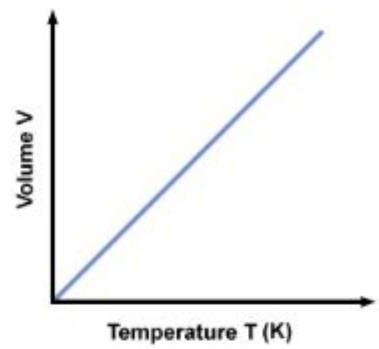
Introduction:

Gases are a state of matter defined as having no commitment to a particular volume or shape. Its subjectivity to change indicates its affected by changes in pressure, volume, and temperature.[1] In a theoretical sense, and *ideal gas* is said to conform to no volume as the particles are too small for any attraction to take place. However, changes in pressure and temperature deviate a gas from ideality, and so the ideal gas law equation is a good indicator of the behavior of a gas subject to these changes:

$$pV = nRT$$

Charles' Law describes the effect of changing temperature on the volume of a gas at a fixed pressure. It can be represented in a graph in which the manipulated independent variable, temperature (K), can increase, leading to a linear increase in the dependent variable, volume (mL).

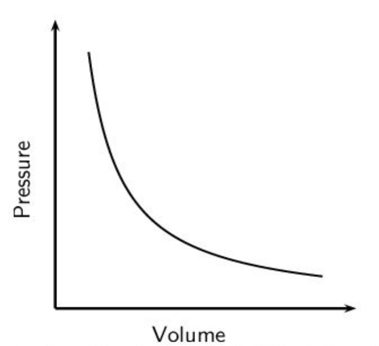


Ling, Nicole. "Charles' Law Graph ." *BRILLIANT*, brilliant.org/discussions/thread/charles-law/.

From the graph, it can be inferred that as temperature increases, the kinetic energy of the particles increase and so the movement of gas molecules are sporadic and collide forcefully so for that reason, more space is occupied (volume). In summary, Charles' Law shows that volume is directly proportional to temperature:

$$V \alpha T$$

Boyle's Law describes the inversely proportional relationship between volume and pressure. At a constant temperature, as volume is increased, the pressure applied to or by a gas will decrease:



V., Stefan. "Boyle's Law Graph ." *Socratic* , socratic.org/questions/why-is-boyle-s-law-graph-curved-1.

It can be seen on the graph that the line seems to approach the x axis but never crosses it because a real gas can never have a volume of zero, despite explaining the relationship of ideal gases in these laws. So, this inversely proportional relationship between the two variables can be shown as such:

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

In this investigation, Charles' Law will be examined by changing the temperature of water involved in the experiment from two extremes: very cold and very hot. This is to get a contrasting result on the effects of temperature on the volume of gas occupied in a flask. Then, Boyle's' Law was tested in order to observe the effects of changing the volume of gas occupied by a 20 mL syringe, on the pressure which was detected by a pressure sensor.

Procedure:

Charles' Law: As described in the Lab Manual ("Do I Dare Disturb The Universe?", Verification of Gas Laws, Dr. Rashmi Venkateswaran, 2018, Exp. 1, pg. 7)

Boyle's Law:

1) Wear lab coat, safety goggles, and tie hair back if needed
2) Prepare the Vernier Gas Pressure Sensor by connecting it to LabQuest 2 (ensure that the variables presented are pressure - kPa, and volume - mL)
3) Obtain a 20 mL gas syringe and move the plunger to the 15 mL mark
    a) 15 mL is a good starting point as the plunger can freely move without much struggle as this value is not too high or too low in comparison to atmospheric pressure.
4) Attach the gas syringe to the Vernier Gas Pressure Sensor by half-turning the syringe to lock it in place (do not turn too tightly as it may strip the threading on the syringe and/or sensor)
5) Set up LabQuest 2 to data collection mode and enter the volume in mL
    a) There is a 0.8 mL of space inside the pressure sensor so ensure all volume readings have 0.8 added to them.
6) Start data collection by holding the plunger at the 15mL mark until the pressure reading stabilizes
7) Record the pressure (add 0.8mL)
8) Repeat steps 6-7 for about 7 trials, reading 7 different volumes and decreasing the volume by 2 mL each trial. For the final volume measurement, move the plunger back to the original 15mL mark.
9) When all data points have been collected, press the stop button
10) Store data in USB then clean bench area

Table 1. Raw Data for Charles' Law Investigation

	Volume - V_1 (±0.1 mL)	*Volume - V_{cw} (±0.1 mL)*	*Volume - V_2 (±0.1 mL)*	*Initial Temperature of Boiling Flask (±0.2℃)*	*Final Temperature of Boiling Flask (±0.2℃)*	*Initial Temperature of Ice Bath (±0.2℃)*	*Final Temperature of Ice Bath (±0.2℃)*
Trial 1	156.5	47.3	109.2	25.2	85.5	5.2	4.3
Trial 2	156.5	90.5	66.0	23.4	80.4	5.4	4.7

* Note: Final temperatures for both boiling flask and ice bath were recorded 6 minutes after the flask reached boiling/freezing temperatures.

Observations:

During the data collection process, there was a foggy appearance inside the flask due to the boiling water, as well as the slight water vapor that was attached to the surface of the flask. This explains the great increase in temperature from the initial to the final as boiling water meant that the air inside the flask was also increasing in temperature. It can be observed from the data however that in the second trial, the final temperature recorded was lower than in the first trial and that can be a result of the flask being inserted inside the beaker immediately after an ice bath and so the air was cooler, as well as large volumes of water evaporated from trial 1 and so when the flask was inserted into the beaker once again, the water was not as filled and so this all ties down to a combination of instrumental and human error. In terms of the ice bath, the flask can be seen clearing up of the fog as well as slight condensation in order to reach a state of equilibrium.

Calculations:

1. Volume (V_1) / temperature pair (T_1) of boiling water
   a. Trial 1: $V_1 = 156.5 \pm 0.1$mL corresponds to $T_1 = 85.5 \pm 0.2$ ℃
   b. Trial 2: $V_1 = 156.5 \pm 0.1mL$ corresponds to $T_1 = 80.4 \pm 0.2$ ℃
2. Calculate V_2, the volume of the gas at T_2 (temperature of ice bath) by subtracting V_{cw} from V_1.
   a. Water from Erlenmeyer flask measured using a Graduated Cylinder:
      i. Trial 1: $V_{cw} = 47.3 \pm 0.1$ mL
      ii. Trial 2: $V_{cw} = 90.5 \pm 0.1$ mL
   b. The volume, V_2, occupied by the gas at temperature T_2
      i. $= V_1 - V_{cw} = (156.5 \pm 0.1\text{mL}) - (47.3 \pm 0.1\text{mL}) =$ 109.2 ±0.2mL corresponds to $T_2 = 4.3 \pm 0.2$℃
      ii. $= V_1 - V_{cw} = (156.5 \pm 0.1\text{mL}) - (90.5 \pm 0.1\text{mL}) =$ 66.0 ±0.2mL corresponds to $T_2 = 4.3 \pm 0.2$℃
3. Verify Charles' Law
   a. $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ (ensure all temperatures are in Kelvin)
      i. $V_1 = 156.5\ mL$
      ii. $T_1 = 85.5$℃ $+ 273.15 = 358.7$K
      iii. $V_2 = ?$
      iv. $T_2 = 4.3$ ℃ $+ 273.15 = 277.5$K
   b. $\frac{156.5}{358.7} = \frac{x}{277.5} \rightarrow 0.4362977418 = \frac{x}{277.5} \rightarrow V_2 = 121.1\ mL$
      i. Theoretically, $\frac{V}{T} = $ k, where k is a constant (0.4362977418). To satisfy the equation, V_2 should = 121. mL in order to follow an ideal gas yet the actual value is 109.2 mL as a result of measurement errors.
4. Calculate averages of measurements:
   Sample Calculation: ($\frac{V_1}{T_1}$)
   Take the ratio of $V_1 : T_1$ and the ratio of $V_2 : T_2$ (ensuring all temperatures are in Kelvin) and calculate the average by adding the the ratios and dividing by 2:

Trial 1: $V_1 : T_1$ = 156.5 : 358.7 Trial 2: $V_1 : T_1$ = 156.5 : 353.6

Add volumes: 156.5 + 156.5 = 313.0→ 313.0/2 = 156.5

Add temperatures: 358.7 +353.6 = 712.3 → 712.3/2 = 356.2

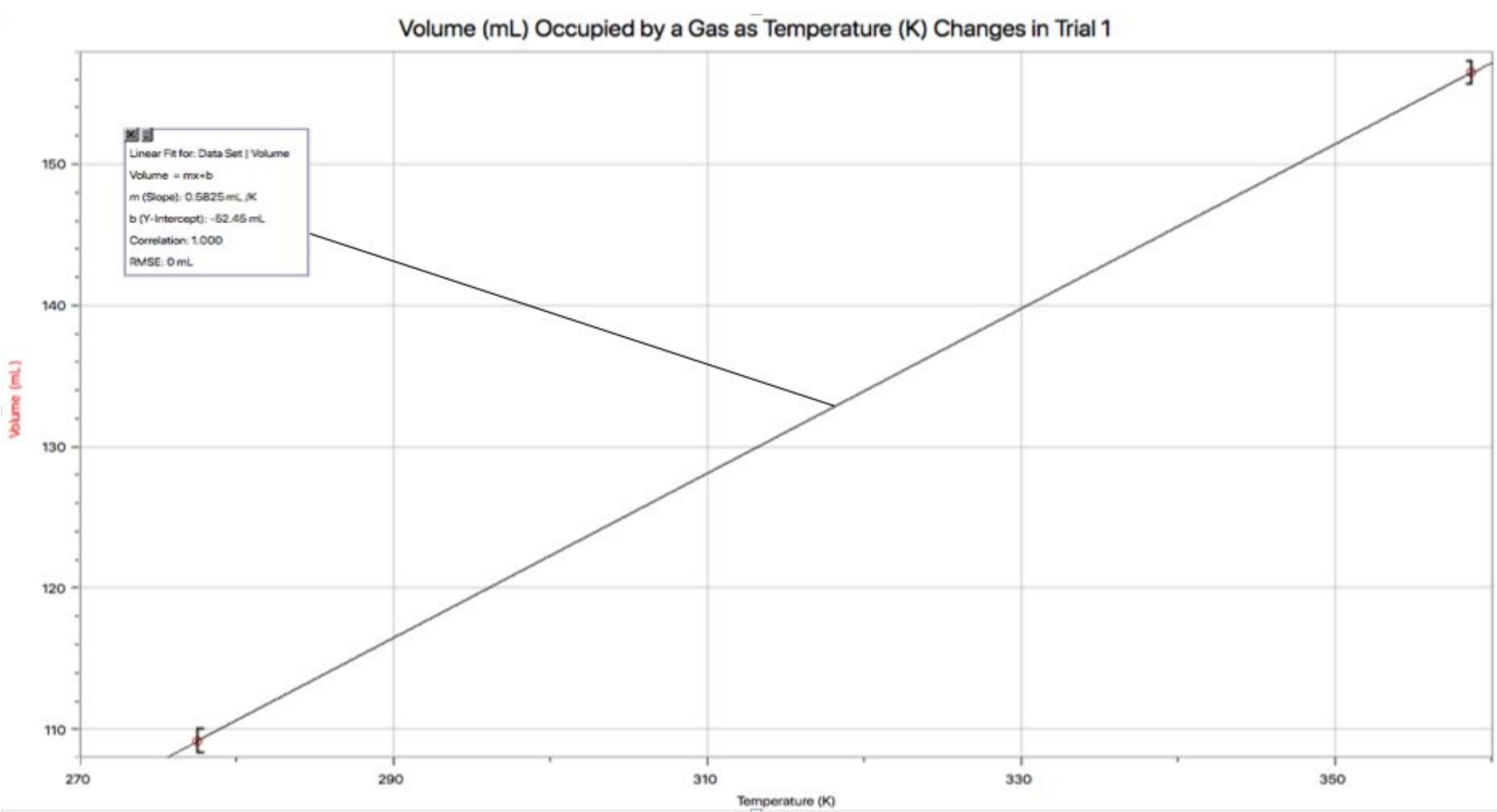
Thus, Average of $\frac{V_1}{T_1}$: $\frac{156.5}{356.2}$

Table 1.1 Processed data for Charles' Law Investigation

	Volume - V_1 (±0.1 mL)	*Temperature of Boiling Flask T_1 (±0.2 K)*	*Volume - V_2 (±0.1 mL)*	*Temperature of Ice Bath T_2 (±0.2 K)*
Trial 1	156.5	358.7	109.2	277.5
Trial 2	156.5	353.6	66.0	277.9
Avg. Ratios ($\frac{V}{T}$)	$\frac{V_1}{T_1}$: $\frac{156.5}{356.2}$		$\frac{V_2}{T_2}$: $\frac{87.6}{277.7}$	

5. Calculate percent error
   a. % Error $= \frac{(V_1/T_1) - (V_2/T_2)}{(V_1/T_1)}$ x100% $= \frac{(156.5/356.2) - (87.6/277.7)}{(156.5/356.2)}$ x100% = 28.2%

Graph 1. Charles' Law - Volume (mL) of a Gas at a Fixed Pressure as Temperature (K) Changes in Trial 1



* Graph of Trial 2 was excluded as the value of Volume 2 (V_2) is an anomaly.

Table 2. Raw Data for Boyle's Law Investigation

Volume (mL) *± 0.5 mL*	*Pressure (kPa)* *± 4 kPa*
~~15.8*~~	~~101.6*~~
13.8	114.5
11.8	133.3
9.8	158.0
7.8	191.4
5.8	224.6
15.8	102.0

* Note: strikethrough indicates that difference between the first and last recording are negligible and therefore the chosen value does not affect results significantly.

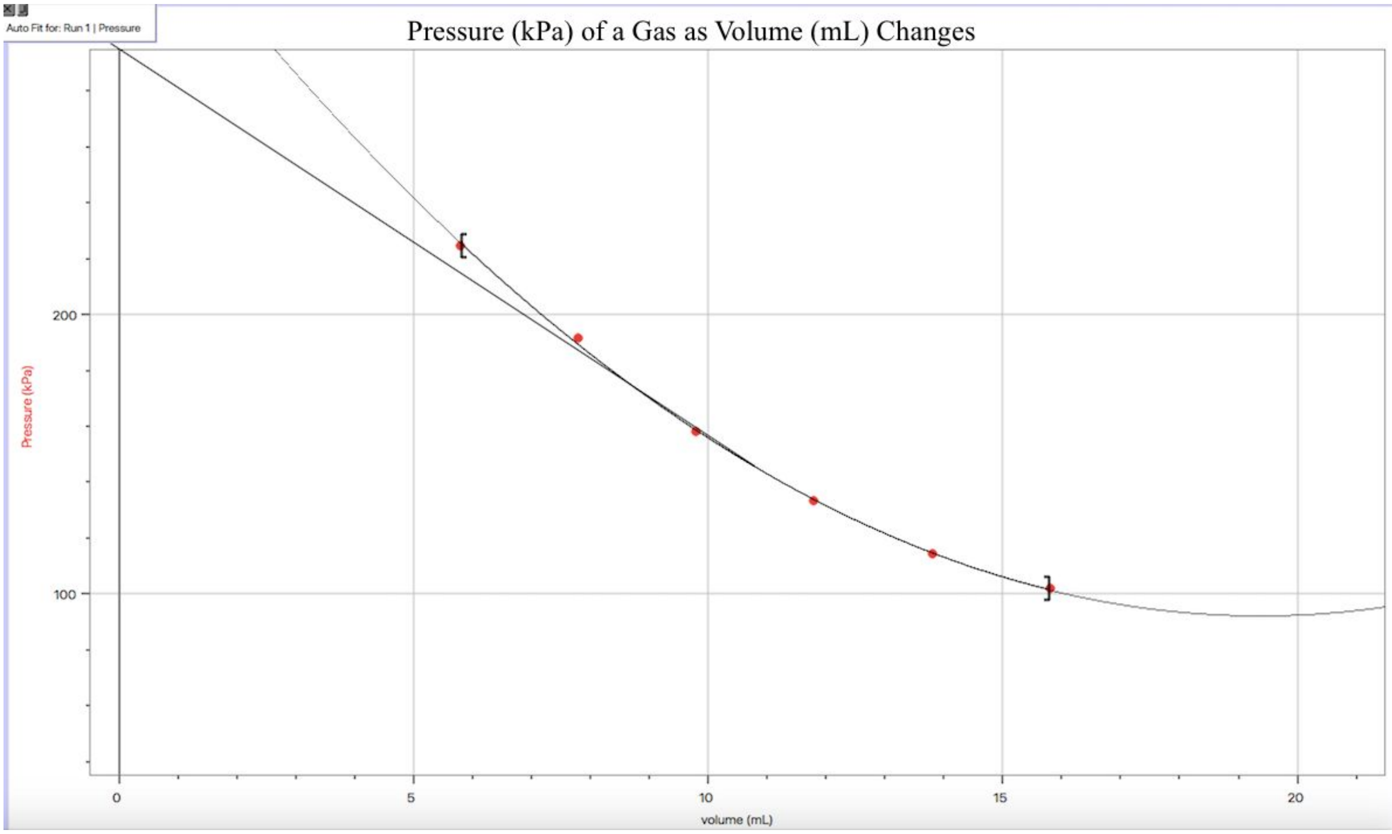
Observations:

During the conduction of this investigation, as the trials progress it becomes difficult to stabilize the plunger due to the high pressure of the gas. This results in the pressure reading to be a bit inaccurate and this has the potential to affect further calculations.

Calculations:

1. Calculate Boyle's Law constant.
   Sample Calculation:
   a. PV = k
   b. (13.8)(114.5) = 1580.1
2. Describe mathematical relationship illustrated and use the constant calculated in step 1 to write an equation for Boyle's law
   a. *As volume of the syringe increases, the pressure inside should decrease as there is more space to be occupied by the air. So, an inversely proportional relationship between volume and pressure arises:*
      i. $P_1V_1 = k$
         1. (13.8)(114.5) = 1580.1
      ii. Then, $P_2V_2 = k$
         1. Then, (11.8)(133.3) = 1573.0
      iii. Therefore, $P_1V_1 = P_2V_2$
         1. (13.8)(114.5) = (11.8)(133.3)
      iv. *Ideally, the constant 1580.1 should remain consistent for every value P and V plugged in. However, due to measurement errors theres slight variation in the k values calculated.*

Graph 2. Boyle's Law - Pressure (kPa) of a Gas at a Fixed Temperature as Volume (mL) Changes



Discussion:

Based on the graph of Charles' law, the proportional relationship between temperature and volume are clearly reflected indicating the data sufficiently verifies this law. Similarly, in Boyle's law graph, the inversely proportional relationship between volume and pressure is clearly reflected. From the data, a pattern can be derived in which the pressure reading of the gas increases, as the volume decreases, therefore verifying Boyle's' law. Despite the results modeling what both laws suggest, there were some errors present comprising of instrumental, human, and systematic errors.

Throughout the conduction of the experiment, there were errors that came about which affected the final results. With Charles' Law, there were instrumental errors such as the hot plate not heating up properly which manipulate the results as the delay in the boiling point could possibly indicate more water loss from the evaporation in the beaker has taken place. This in turn, affects the air inside the Erlenmeyer flask as it may not have been hot enough due to the decreased volume of water, leading to inaccurate recordings of temperature (T_1) data. Human error was present as the Erlenmeyer flask was hot to the point where it was difficult for the conductors to hold the stopper, as heat was burning the fingers. This means that some air could have escaped as well as been exposed to the room temperature of the laboratory, which could in turn cool down the flask unintentionally. This can affect the verification of charles' law calculations as results may be inaccurate, which can be supported by the percent error, 28.2%. A closely related systematic error would be the repetition of trials back to back, as the flask from the ice bath (from trial 1) was immediately inserted back into the boiling beaker (for trial 2), affecting readings as observed in the lower values of volume and temperature in trial 2. It is important to note that during the second trial, the level of water in the flask and the level of water in the ice bath didn't directly match, resulting in too much water to enter the flask and when transferred to a graduated cylinder, the reading was inaccurate (90.5 mL). This also affected the processed data as it resulted in the anomaly observed, 66.0 mL.

With Boyle's Law, the main source of error would be the lack of stability as the volume decreased for each trial since the pressure was very high inside the syringe and therefore the resistance factor affected the pressure reading. This partly explains why the first and last measurement were taken at the same mark in order to choose a value that more closely fit the remaining data points. In this case however, both pressure readings at volume 15.8 mL were similar meaning the difference is negligible and so the value chosen had no significant effect on the data. What does affect the results however, is certain conditions to be met for other gas variables. Boyle's conducted experiment worked with a fixed amount of air trapped in a glass tube, so *n* was held constant. He also worked at only one temperature so *T* remained constant.[2] This means that the amount (moles) and temperature inside the syringe should be held constant. As observed from calculating Boyle's Law constant, these two conditions weren't met throughout the conduction of the experiment as the constant, k, slightly differs from one PV calculation to another.

Conclusion:

The values obtained for Charles' law include $\frac{V_1}{T_1}$: $\frac{156.5}{356.2}$ and $\frac{V_2}{T_2}$: $\frac{87.6}{277.7}$ respectively, at a fixed pressure. The derived Boyle's Law equation is $P_1V_1 = P_2V_2$ in which any two pressure and volume points input should equal each other as the temperature and amount is kept constant, k.