Verification of Gas Laws

Written by:

Nicholas Fillmore, (student number)
and
Gruia Pituscan, (student number)

TA: Vanessa Suserski

Date: Tuesday, September 25, 2018

Theory:

A gas is defined as a state of matter in which particles move freely and the substance does not retain any shape or volume. Many studies of gases have been done by numerous scientists, notably Jacques Charles and Robert Boyle. Charles developed a law that states that at a constant pressure and amount of substance, the volume of a fixed amount of gas divided by its temperature is equal to a constant. Therefore, volume is proportional to temperature. Boyle developed a similar law that states that at constant temperature, the volume of a fixed amount of gas multiplied by its pressure is also equal to a constant, making volume inversely proportional to pressure. Both of these equations are forms of the ideal gas law PV=nRT.[1]

The purpose of this lab is to verify Charles' and Boyle's gas laws using experimental evidence. For Charles' law, the experiment involves heating the air inside a beaker, then cooling it so it contracts, and measuring what change in volume is associated with what change in temperature. As Charles' law states, any volume of air divided by the temperature of the air will equal a constant. For Boyle's law, the volume of air in a syringe is decreased, thus increasing pressure, according to the law which states that pressure times volume is equal to a constant. The pressure is recorded using a sensor and then compared to the volume.

MATERIALS

- 125 mL Erlenmeyer flask
- 600 mL beaker
- Stopper with hole
- Thermometer
- Ice bath
- Extension clamp
- LabQuest 2
- Vernier Gas Pressure Sensor
- 20 mL gas syringe
- USB key

PROCEDUREs

CHARLES' LAW

1. Obtain a clean Erlenmeyer flask.
2. Place a rubber stopper in the top of the flask and mark the bottom of the stopper.
3. Fill the 600 mL beaker with water.
4. Place the beaker on the hot plate.

---

[1] Tenny, K. M., & Cooper, J. S. (2018, February 09). Chemistry, Ideal Gas Behavior. Retrieved from http://europepmc.org/books/NBK441936;jsessionid=678AB01C1E58312D5418B1C46D6A721B

5. Clamp the Erlenmeyer and submerge it in the beaker of water.
6. Turn the hot plate on and allow the water to boil. When the water is boiling allow the Erlenmeyer to remain for 6-7 minutes.
7. Prepare a large ice bath.
8. Place a finger over the hole in the stopper and without removing it, take the Erlenmeyer and submerge it in the ice bath. Once the mouth is submerged, remove finger. Leave Erlenmeyer in ice bath for 5-6 minutes to allow temperatures to balance out.
9. Record temperature of ice bath.
10. Adjust height of flask so water level matches between flask and bath.
11. Place finger on hole in stopper and remove flask.
12. Transfer volume of water in Erlenmeyer to a graduated cylinder. Record its volume as Vcw. This corresponds to T2 (the measured temperature of the ice bath in step 9)
13. Fill the Erlenmeyer to where the bottom of the stopper was marked. Record this volume of water and call it V1.

BOYLE'S LAW

1. Attach the syringe to the gas pressure sensor and connect the sensor to Labquest. NOTE: do not screw the syringe on all the way! A half twist will do. If the syringe is attached too tightly it can break at high pressures.
2. Set the syringe to 10 mL of gas. This will allow enough of a decrease in volume without pressure becoming too difficult to control. Volume will act as the independent variable in the experiment and pressure is the dependent variable while temperature is kept constant.
3. Decrease the volume in increments of 1 mL, 6-8 times. Record the pressure for each of these volumes in Labquest and on paper, adding 0.8 mL to each volume because there is 0.8 mL of space inside the sensor.
4. For the final measurement, repeat the first volume and decide which measurement of pressure to keep for the first volume.
5. Use Labquest to graph the data. Choose a function to use as a curve of best fit.

TABLES

Table 1: Temperatures of Erlenmeyer flask and its environment

Environment	Temperature (degrees Celsius)
Boiling water	102.5
Ice bath before Erlenmeyer inserted	8.8
Ice bath after Erlenmeyer inserted	14.0

Table 2: Volumes in Erlenmeyer

Stage of experiment	Volume
V1, initial volume of gas in Erlenmeyer	148.5
Vcw, volume of water entering Erlenmeyer	30.5
V2, final volume of gas in Erlenmeyer (V1-Vcw)	118.0

Table 3: Volume of gas in syringe vs. pressure

Volume (mL)	Pressure (kPa)
9.8	101.32
8.8	113.54
7.8	118.75
6.8	143.21
5.8	169.27
4.8	203.76

Observations: - The volume of gas in the Erlenmeyer had to decrease to allow the water to enter.
-The temperature decreased as this was happening.
-The pressure increased as the volume decreased.

GRAPHS

Figure 1, Volume of gas in syringe vs. pressure

DATA ANALYSIS_and CALCULATIONS

Charles' Law

1. V_1 = 148.5 mL T_1 = 102.5°C
   = 375.65K

2. V_2= V_1 - V_{cw} T_2 = 14°C
   = 287.15K

   V_2= 148.5 mL-30.5 mL
   V_2= 118.5 mL

3. Charles's Law states that $V_1T_2 = V_2T_1$. To verify such a relation one must substitute the experimental values in their respective positions thus,

$$V_1T_2 = V_2T_1 \quad = \quad (148.5\ mL)(\ 287.15K\ ) = (118.5\ mL)(375.65K)$$
$$42641.775 = 44514.525$$

While these values are not exactly equivalent, this may largely be due to potential experimental or inherent errors in the procedure. Small factors such as the beaker spending extended time outside of water or simple misreadings of data multiply to produce discrepancies that seem larger than s light error. The exact value of such error is elaborated on and calculated in question 5.

4. N/A . Time was limited with the lab introductions and unfamiliarity with the lab itself such that it was decided that 1 experiment would be done well as opposed to two being rushed and sloppy.

5. Percent Error is the value that account for the potential aforementioned mistakes and misreadings throughout the course of the experiment. It allows one to identify the distance from their experimental values to the theoretical or literary values. It may be calculated as follows,

   % Error = $(V_1/T_1 - V_2T_2)/V_1/T_1 * 100\%$
   % Error = (148.5 mL/375.65K - 118.5 mL/ 287.15K)/148.5 mL/375.65K *100%
   % Error = 4.39%

Boyle's Law

1. Boyle's law constant may be found by incorporating all pairs of Volume and Pressure values and multiplying them in the same way as Boyle's Law itself to discover the constant in reverse.

#1- V = 9.8 mL
P = 101.32 kPa
Let k = the Boyle's law constant

k = VP
k_1= (9.8 mL)(101.32 kPa)
= 992.936 mL kPa

#2- V = 8.8 mL
P = 113.54 kPa

k_2= (8.8 mL)(113.54 kPa)
= 999.152 mL kPa

#3- V = 7.8 mL
P = 118.75 kPa
k_3 = (7.8 mL)(118.75 kPa)
= 926.25 mL kPa

#4- V = 6.8 mL
P = 143.21 kPa
k_4 = (6.8 mL)(143.21 kPa)
= 973.828 mL kPa

#5 - V = 5.8 mL
P = 169.27 kPa
k_5 = (5.8 mL)(169.27 kPa)
= 981.766 mL kPa

#6 - V = 4.8 mL
P = 203.76 kPa
k_6 = (4.8 mL)(203.76 kPa)
= 978.048 mL kPa

$k_{av} = (k_1 + k_2 + k_3 + k_4 + k_5 + k_6)/6$
= (992.936 + 999.152 + 926.25 + 973.828 + 981.766 + 978.048) mL kPa/6
k_{av} = 975. 33 mL kPa

2. If the equation used in #1 is rewritten, the result is:

V = k / P **or** P = k/V

This is a reciprocal relationship, where one variable is equal to a constant divided by the other variable. In this case, the exact equation is

V = 975.33 mL kPa / P

3. The reason for repeating the first trial is to eliminate inaccuracies. With two values, an average can be calculated, which removes some error from the values, or whichever value seems to be an outlier can be eliminated. This allows for more consistent and reliable data.

4. The gas variables that remained constant in the experiment were temperature and amount of substance. First, temperature was kept constant by not exposing the syringe-sensor system to any substances that were hotter or colder than room temperature, keeping the temperature of the system in equilibrium with the temperature of the room. Second, the amount of gas was kept constant by keeping the system closed, preventing any of the substance from escaping the system. It is possible that these values were not kept perfectly constant. For example, touching the syringe transfers heat from the person's hand to the system. Similarly, small undetected cracks or holes would allow for the amount of substance to decrease because it is escaping the system (however, if there were any such holes they are most likely too small to affect results. Increases or decreases in these values would result in a directly proportional increase or decrease of the Boyle's law constant (because PV=nRT).

5. See graphs above

DISCUSSION

The results seem to verify both gas laws. In the first experiment, the initial value of volume divided by the initial temperature, and the final volume divided by the final temperature, yielded very similar values. This seems to suggest that volume divided by temperature is equal to a constant, as Charles' law states. In the second experiment, the volume multiplied by the pressure gave a very similar value every time. This suggests Boyle's law - that volume times pressure gives a constant. Despite this evidence, there are certain sources of error in the experiment that make the results less credible. For example, multiple trials of the first experiment were not carried out. This means any source of error - whether human or experimental - is magnified in the results. If multiple trials were done and an average was taken, the results would reflect reality more because they would tend towards the actual Charles' Law constant. Furthermore, some of the measuring techniques create inaccuracies. For example, when the water was used to measure volume of gas in the container, it was transferred from the flask to a graduated cylinder. Some water was left behind in the flask or clung to the side of the graduated cylinder. All these drops of water added up likely lead to a slightly different volume, a more accurate one.

In the second experiment, a major source of error is the LabQuest machine and pressure sensor. The sensor could not pick up a constant pressure even when the syringe was perfectly still. The value of pressure would always be around a certain value for pressure (assumed to be the correct value) but the sensor would alternate between higher and lower pressures than the actual one. This made it hard to tell what the actual pressure was and created inaccuracies in the values of pressure. Furthermore, the values for volume are somewhat inaccurate. The syringe is very small, and what is actually 0.9 mL may actually be 1 mL. Although this is not a huge difference, the values for volume only have 2 significant figures so this difference creates a noticeable inaccuracy in calculations.

Overall, this experiment could have used more sophisticated technology to detect volume, temperature and pressure. This would eliminate much of the human error and error caused by imprecise measuring equipment.

CONCLUSION

The results verify the two gas laws. In the case of Charles' law, the ratio of volume to temperature is roughly the same (42641.775, 44514.525) throughout the experiment, and in the case of Boyle's law, the volume times the pressure is always roughly equal to the constant 975.33 mL kPa.