The Verification of Boyle's Law and Charles' Law

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Introduction:

Gases

Gases are one of the fundamental states of matter consisting of particles with variable shape and volume.[5] These variabilities cause gases to be affected by modifications of temperature, pressure, and volume.[3] Particles of gases are dispersed at a distance from each other, due to this, most gases are transparent.[5] At low temperatures, gases contract and move slower, the volume is also decreased. The relationship between temperature and volume is known as Charles' Law. At high temperatures, gases expand and move faster, the pressure increases while the volume decreases. The relationship between pressure and volume is known as Boyle's Law. [9]

Ideal Gases

An ideal gas is a hypothetical gas that contains particles that do not interact with each other and has no volume. Real gases are unpredictable, they tend to collide and sometimes interact with each other. Ideal gases are used to model the behaviour of a gas in an ideal state. When conducting experiments, it is assumed that the experimental gas is an ideal gas. [10] Ideal gases have pressure, volume, and temperature that are related by the ideal gas law. The equation that models this relationship is:

$$PV = nRT \quad [6]$$

Charles' law

Charles' law is defined as the proportional relationship between volume and temperature when pressure remains constant.[2] This law is applicable to ideal gases whose pressures are constant, and the temperature and volume are changed.[7] When a gas with a constant pressure has a temperature increase, the volume increases proportionally. Inversely, when the gas is at a low temperature , the volume decreases proportionally.[2] This relationship is expressed in the following equation:

$$V_1 / T_1 = V_2 / T_2 \quad [7]$$

Boyle's law

Boyle's law is defined as the inverse relationship between pressure and volume when temperature is held constant. As the volume of the gas decreases, the pressure of the gas increases proportionally. Inversely when the volume of the gas increases, the pressure decreases proportionally. This relationship is expressed by the equation: $P_1V_1 = P_2V_2$ [8]

Concepts of experiment

In this experiment, the two gas laws, Charles' law and Boyle's Law will be verified by conducting two individual experiments for the gas laws.In the verification of Charles' law, air will be confined in a flask where it will be place into two extreme temperatures in order to observe clear volumetric changes. During the verification of Boyle's law, air will be confined in a 20 ml syringe and connected to a pressure sensor and observed for pressure changes as volume is adjusted. [4]

Procedure:

Charles' Law: As described in the lab manual (Dr. Rashmi Venkateswaran,What in the World ISN'T Chemistry, 2018, Exp. 1, p. 1).

Boyle's Law:

1. Gather all materials and apparatus needed for this experiment. Ensure that proper lab attire(lab coat, safety goggles, closed toe shoes, long pants) are worn.

2. Connect the Gas pressure sensor to the Labquest 2 and turn it on. Move the plunger of the plastic plunger of the plastic syringe to the initial volume mark, 11 ml where the tip of the plunger is touching the target volume.(Note: the volume readings need to be corrected by adding 0.8 ml when inputting data into Labquest 2).
3. Attach the 20 ml syringe to the valve of the gas pressure sensor.
4. Hold the plunger at the initial mark and record pressure. Move the plunger to the next target volume, 5 ml, and record the pressure. Continue this for the next five set volumes, 8 ml, 3 ml, 15 ml, 13 ml, 18 ml. After this, move the plunger back to the initial mark and record the pressure.
5. Repeat steps 2-5 for the second trial.
6. Clean up station and put away all equipment.

Tables:

Charles Law: The Volume vs Temperature Data of the gas sample at 101.3 kPa

Trials	Initial Temperature of the Air (K)	Initial Volume of the Air (ml)	Final Temperature of Air (K)	Volume of Water in the Flask (V_{cw}) (ml)	Final Volume of the Air (ml)	Pressure* of Air (kPa)
1	373	153	278.15	35	118	101.3
2	373	155	278.15	33	122	101.3

**using the estimated atmospheric pressure.[1]*

Boyle's Law:

Trial 1: Pressure vs Volume Data for a gas sample, Air, at 296.15 K in the first trial

Volume (ml)	Pressure (kPa)	Temperature (K)
3.8	225.30	296.15
5.8	210.10	296.15
8.8	136.31	296.15
11.8	101.21	296.15
11.8	101.79	296.15
13.8	86.37	296.15
15.8	77.23	296.15
18.8	64.13	296.15

Trial 2:Pressure vs Volume Data for a gas sample,Air, at 296.15 K in the second trial

Volume (ml)	Pressure (kPa)	Temperature (K)
3.8	225.31	296.15
5.8	215.18	296.15
8.8	135.62	296.15
11.8	101.07	296.15
11.8	100.80	296.15
13.8	86.42	296.15
15.8	76.96	296.15
18.8	64.38	296.15

Observations:

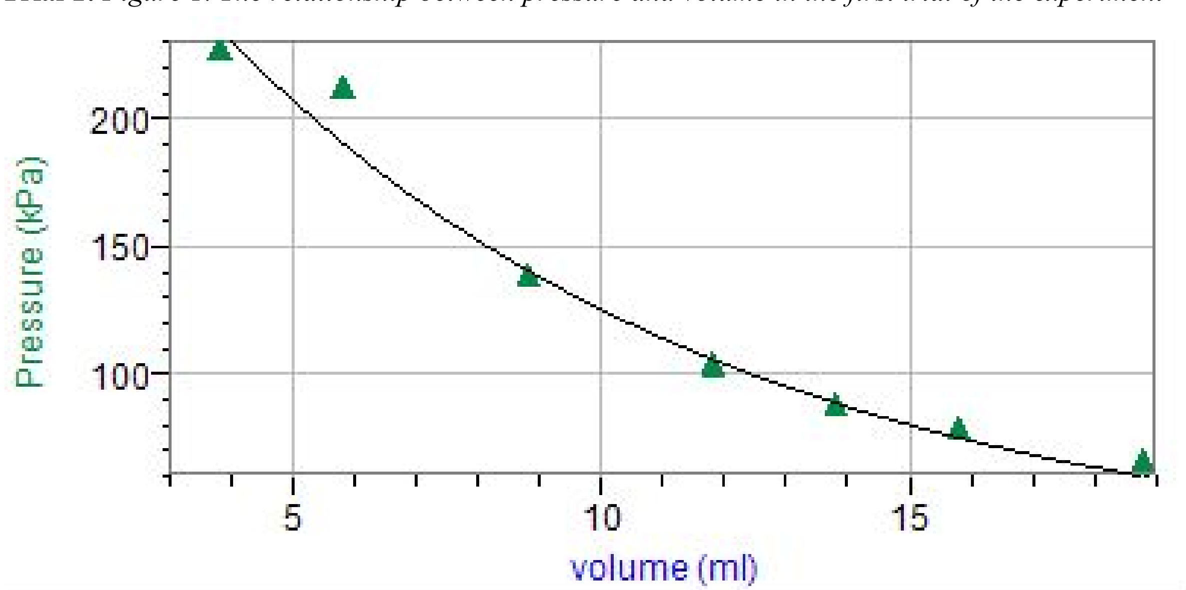
Charles Law: During the lab, while the hot water began to boil with the flask inside the beaker, the flask slowly began to become the same temperature as the beaker. When the flask was placed into the ice bath the water in the ice bath began to go into the flask through the hole in the stopper.

(Note: the experiment had to be reconducted after the first trial following the discovery of the air bubbles in the flask)

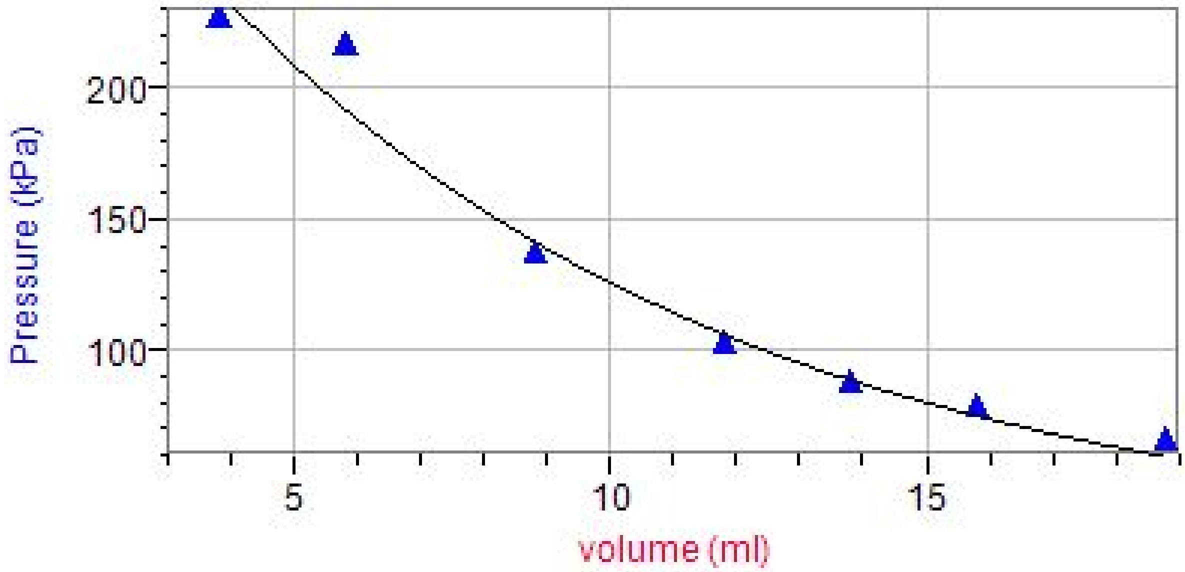
Boyle's Law: During the experiment when testing the different volumes, as the volume decreased, it became very difficult to compress the plunger of the syringe, which indicated an increase in pressure on the plunger by the air inside the syringe.

Graphs:

Trial 1: *Figure 1. The relationship between pressure and volume in the first trial of the experiment*



Trial 2: *Figure 2.The relationship between pressure and volume in the second trial of the experiment*



Calculations:

a) Trial 1: $V_2 = V_1 - V_{cw}$
$= 153$ ml - 35 ml
$= 118$ ml
Trial 2: $V_2 = V_1 - V_{cw}$
$= 155$ ml - 33 ml
$= 122$ ml

b) $V_1 / T_1 = V_2 / T_2$
153 ml /373 K = 118 ml/ 278.15 K
0.410 ml/K = 0.424 ml/K
*****values may not be equal but are very closely equal, this is caused by experimental error throughout the lab*

c) Avg. Initial Volume = Trial 1+ Trial 2/ 2
= 153 ml + 155 ml /2
= 154 ml
Avg. Initial Temperature = Trial 1+ Trial 2/ 2
= 373 K + 373 K /2
= 373 K
Avg. Final Temperature = Trial 1+ Trial 2 /2
= 278.15 K + 278.15 K/ 2
= 278.15 K
Avg. Volume of water in flask = Trial 1+ Trial 2 / 2
= 35 ml + 33 ml/2

= 34 ml

Avg. Final Volume = Trial 1 + Trial 2 / 2

= 118 ml + 122 ml/2

= 120 ml

Avg. Pressure = Trial 1 + Trial 2 /2

= 101.3 kPa + 101.3 kPa/ 2

= 101.3 kPa

d) % error = $V_1/ T_1 - V_2/T_2 \ / V_1/ T_1 \times 100$ %

= 153 ml/373 K - 118 ml/278.15 K / 153 ml/ 373K × 100 %

= 0.410 ~~ml/K~~ - 0.424 ~~ml/K~~ / 0.410 ~~ml/K~~ × 100 %

= -3%

e) PV= k

i) 3.8 ml × 225.30 kPa = 8.6×10^2 ml*kPa

ii) 5.8 ml × 210.10 kPa = 1.2×10^3 ml*kPa

iii) 8.8 ml × 136.31 kPa = 1.2×10^3ml*kPa

iv) 11.8 ml × 101.21 kPa = 1.2×10^3ml*kPa

v) 11.8 ml × 101.79 kPa= 1.2×10^3ml*kPa

vi) 13.8 ml × 86.37 kPa = 1.2×10^3ml*kPa

vii) 15.8 ml × 77.23 kPa = 1.2×10^3ml*kPa

viii) 18.8 ml × 64.13 kPa = 1.2×10^3ml*kPa

Avg. of k, constant = all values added / 8

= (1.2×10^3 ml*kPa)(7) + 8.6×10^2 ml*kPa / 8

= 1.2×10^3ml*kPa

f) If PV=k,

Then, P_1V_1= k and P_2V_2= k

Meaning PV=PV

Which translates to $P_1V_1 = P_2V_2$

Proof:

PV= k

5.8 ml × 210.10 kPa = 1.2×10^3 ml*kPa

PV=k

11.8 ml × 101.21 kPa = 1.2×10^3ml*kPa

Thus,1.2×10^3 ml*kPa = 1.2×10^3 ml*kPa

Essentially meaning PV=PV

Discussion:

This experiment focused on verifying the two gas laws , Charles' law and Boyle's law. This was achieved through observing the relationship between the dependent and independent variables in both gas laws. As a result, both laws were verified and proven to be correct.

During the first trial of the verification of Charles' law, when the flask was placed into the ice bath, there were air bubbles present in the flask which meant that the trial had to be reconducted. In doing so, the first trial was conducted where the independent variable was adjusted from 373 K to 278.15 K which resulted in the volume also decreasing from 153 ml to 118 ml. During the second trial, there was a similar outcome where the volume was adjusted from 373 K to 278.15 K and the volume proportionally decreased from 155 ml to 122 ml. These results correlated to Charles law where it states that temperature and volume have a proportional relationship when pressure remains constant. The results obtained from the experiment verified that Charles law is correct. However, the percentage error was calculated to be -3%. A potential error which could have occurred during the experiment was inaccurate measurements of the initial volume and the volume of the water in the flask. When these volumes were measured, they could have been potentially read inaccurately which caused a difference in the results which in turn caused an error. Although there was an error present in the lab, this did not falsify Charles' law as the error was very minimal.

The verification of Boyle's law was conducted through the use of a 20 ml syringe and a pressure sensor. The independent variable, volume, was adjusted in an effort to observe the changes in pressure. When the volume of the gas was adjusted within the syringe, the pressure was greatly affected. During the first trial, it was noted that as the volume decreased, the pressure increased. This also occurred in the second trial. The initial point, 11.8 ml, of the independent variable was measured twice in an effort to ensure a more accurate result when comparing the value to other volumes. Despite this, when the Boyle's law constant was calculated, it was noted that most of the values calculated resulted in the constant equalling,1.2×10^3 ml*kPa. However, when the value 3.8 ml and its pressure were multiplied, the constant equaled 8.6×10^2 ml*kPa. This result was due to an error occurring during the experiment. This error could have occurred during the moving of the plunger to a different volume, particularly to a smaller volume, it became more difficult to push the plunger to the selected volume mark. This could have resulted in an inaccurate reading of the pressure due to not accurately reaching the selected volume. The general observation made during the experiment was that as the volume increased/decreased, the pressure increase/decrease was inversely proportional to its volume. This observation suggested that Boyle's law was correct as the law states that pressure and volume have an inverse relationship when the temperature remains constant. This experiment was conducted at room temperature and remained that way throughout the experiment. This allowed Boyle's law to verified in the most effective way despite the minimal error.

Conclusion:

The gas laws were verified experimentally through observing the relationships between their variables where there was a constant. Charles' law was proven to be true as when the temperature decreased, the volume also decreased proportionally. Boyle's law was also proven to be true as when the volume increased the pressure decreased and when the volume decreased, the volume increased. The percentage error calculated for Charles' law was -3%.

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Trial 1

	Run 1	
	volume (ml)	Pressure (kPa)
1	11.8	101.21
2	5.8	210.10
3	8.8	136.31
4	3.8	225.30
5	15.8	77.23
6	13.8	86.37
7	18.8	64.13
8	11.8	101.79
9		
10		

Trial 2

	Run 1	
	volume (ml)	Pressure (kPa)
1	11.8	101.07
2	5.8	215.18
3	8.8	135.62
4	3.8	225.31
5	13.8	86.42
6	15.8	76.96
7	18.8	64.38
8	11.8	100.80
9		
10		
11		
12		
13		