

Verification of Gas Laws

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Experiment 1 → Verification of Gas Laws

Introduction:

Gases behave differently than other types of matter. A gas' temperature, volume, and pressure all rely on one another. The ideal gas law can explain this phenomena within a wide range of temperatures and pressures, however, when the variables reach extremes, real gases tend to deviate from the predictions of the ideal gas law. The ideal gas law is as follows:

$$PV = nRT$$

Where P is pressure in atmospheres, V is volume in litres, n is number of moles, R is the gas constant, and T is the temperature in Kelvin. If the number of moles stays consistent through a change in the variables P, V, and/or T then the change can be documented using:

$$(P_oV_o)/T_o = (P_1V_1)/T_1$$

Derivation of $(P_oV_o)/T_o = (P_1V_1)/T_1$

Equation 1 Equation 2

$$P_oV_o = nRT_o \quad P_1V_1 = nRT_1$$

$$nR = (P_oV_o)/T_o \quad nR = (P_1V_1)/T_1$$

$nR = nR$ ∴ set equations equal to each other

$$(P_oV_o)/T_o = (P_1V_1)/T_1$$

This is called the combined gas law and it shows the relationship between the three variables such that pressure is directly proportional to temperature and inversely proportional to volume.

$$P \propto T/V$$

Using the ideal gas law, Robert Boyle found that an ideal gas kept at a constant temperature would abide by the following equation:

$$PV = k$$

Where k is a constant. This is called Boyle's Law. The lab exercise worked to verify this law by measuring the pressure of a given amount of air inside a syringe as the volume was restricted and expanded.

Furthermore, Jacques Alexandre Charles found that an ideal gas kept at a constant pressure would make it possible to observe the relationship between volume and temperature. Based on the ideal gas law, the following proportionality can be found:

$$V \propto T/P$$

Using this proportionality, Charles discovered that the volume of a gas is equal to the temperature multiplied by a constant. This is called Charles and Gay-Lussac's Law and it is as follows:

$$V=kT$$

Where k is a constant. In the lab exercise this law was tested by heating an Erlenmeyer flask of air with an open top in a container of boiling water before covering the opening and submerging the flask of heated air into an ice bath to rapidly cool the gas. After the cooling is complete, the covering is removed from the top of the flask and the change in volume of the gas should make the water from the ice bath rush in to fill the empty space.

The end goal of both experiments mentioned above is to enhance precursory knowledge about Boyle's Law, Charles and Gay-Lussac's Law, and the Ideal Gas Law learned in the CHM 1311 curriculum

by studying and observing the behaviours of real gases under specific and regulated conditions. The experiments will also supplement the students’ basic laboratory skills by heightening their abilities to follow instructions, operate safely in the lab, and use equipment such as the pressure sensor and LabQuest2.

Procedures:

Verification of Boyle’s Law

1. Gas Pressure Sensor (GPS) was set to having pressure as the dependant variable and volume as the independent variable
2. 10ml of gas was collected in the 20ml syringe and attached to the GPS
3. LabQuest2 was set to data collection mode
4. Pressure value was recorded for 10ml of gas in the syringe
5. Syringe was adjusted to hold 9ml of gas. Pressure value was recorded for 9ml.
6. Step 4 was repeated for 8ml, 7ml, 6ml, 5ml, and 10ml again.

Verification of Charles and Gay-Lussac’s Law: As described in the lab manual (Verification of Gas Laws, Dr Rashmi Venkateswaran, 2018, Exp. 1, p. 6-8)

Observations:

Part A: When the empty Erlenmeyer flask was transferred from the breaker full of boiling water to the ice bath, 39.9ml of cold water shot rapidly into the flask through the rubber stopper when the finger was removed from the top.

Table 1. Data collected in the 3 trials to prove Charles’ Law

Data	Trial 1	Trial 2	Trial 3
Boiling Temperature of Breaker (°C)	101.2	101.3	103.5
Ice Bath Temperature (°C)	14.1	8.0	15.9
Water Volume in Erlenmeyer flask after transfer (ml)	49.2	39.9	31.3

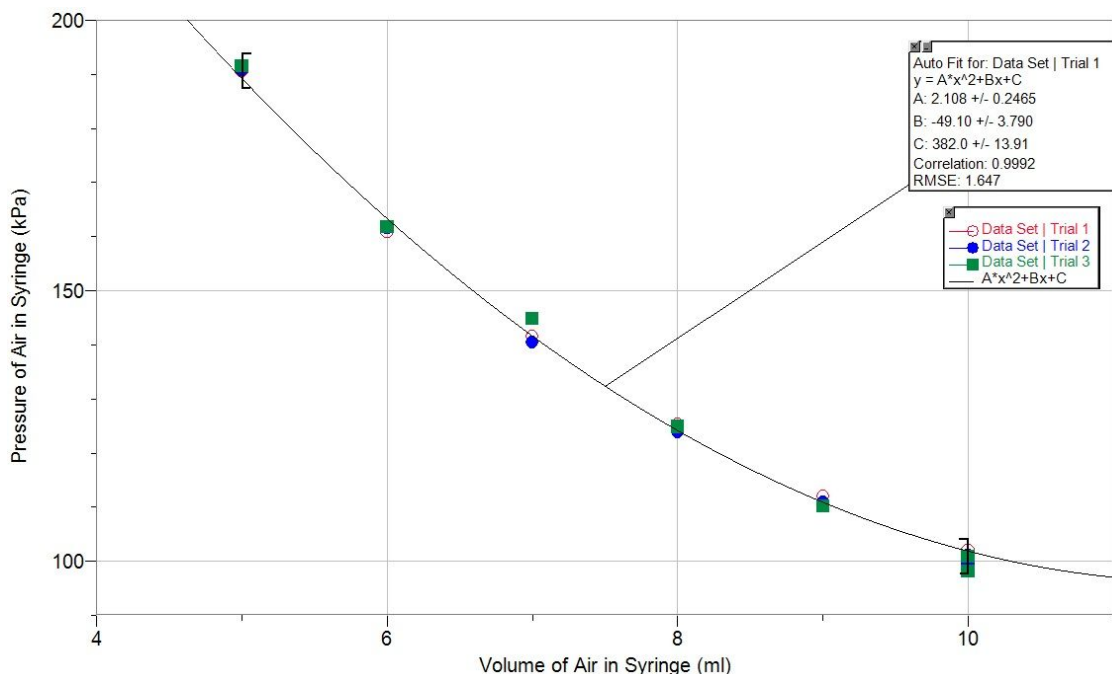


Figure 1. Relationship between the volume of air and the pressure in the syringe

Part B: As the volume in the syringe decreased, the pressure in the syringe greatly increased. This was determined by the values shown on LabQuest2 and the increased effort it took to lower the volume of air inside the syringe as the volume decreased.

Table 1. Data collected in the 3 trials to prove Boyle’s Law

Volume (ml)	Trial 1 Pressure (kPA)	Trial 2 Pressure (kPA)	Trial 3 Pressure (kPA)
10	100.87	100.94	100.87
9	111.56	110.91	110.14
8	125.27	123.91	124.82
7	141.48	140.39	144.87
6	160.98	161.69	161.75
5	190.64	190.77	191.54
10	101.97	99.80	98.17

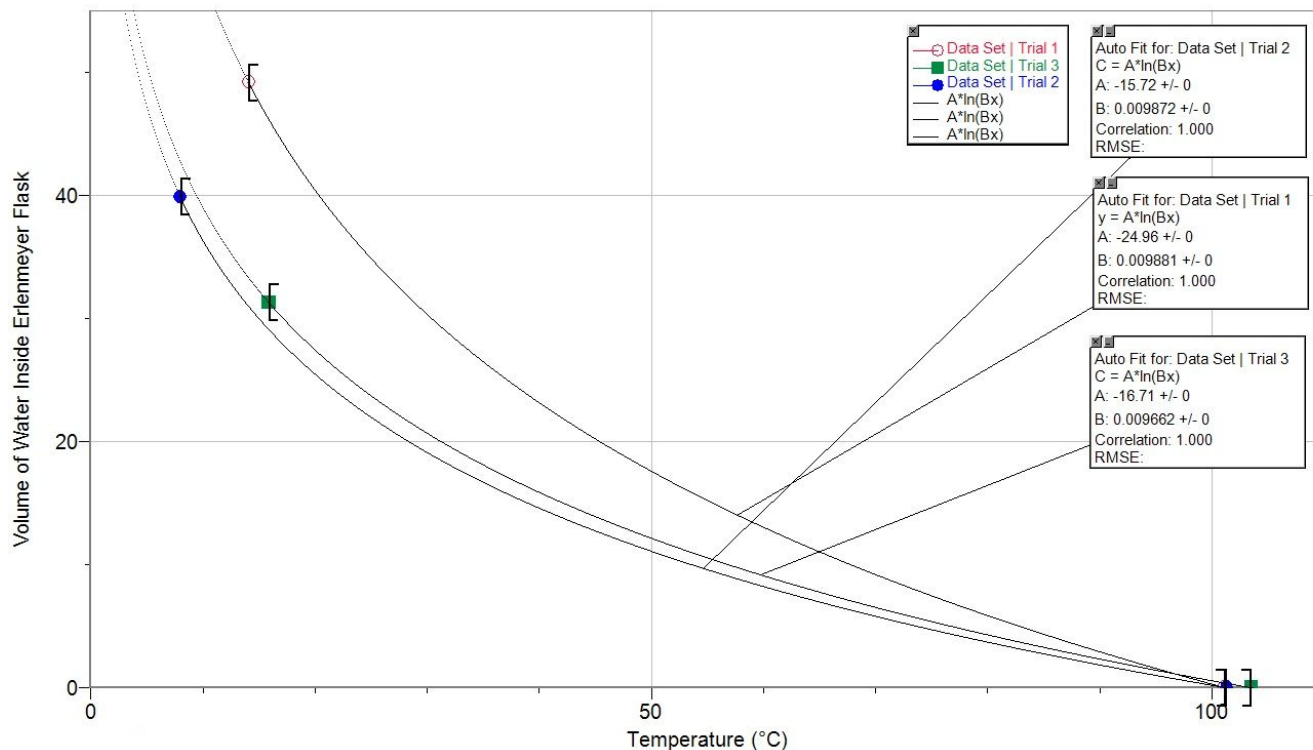


Figure 2. The relationship between the temperature and the volume of water collected in the Erlenmeyer flask.

Calculations:

Part A: (examples taken from trial 2)

1) $V_{\text{gas}} = \text{initial} - V_{\text{water}}$ (Determining the volume of gas in the Erlenmeyer flask)
 $V_{\text{gas}} = 150 \text{ ml} - 39.9 \text{ ml}$
 $V_{\text{gas}} = 110.1 \text{ ml}$

2) $\Delta T = |t_2 - t_1|$ $t_2 = \text{ice bath temperature}$
 $\Delta T = 18.0^\circ\text{C} - 101.3^\circ\text{C}$ $t_1 = \text{hot plate beaker temperature}$
 $\Delta T = 93.3^\circ\text{C}$

3) $V = kT$ $\Delta V = V_{\text{water}}$
 $k = \frac{\Delta V}{\Delta T}$
 $k = \frac{39.9 \text{ ml}}{93.3^\circ\text{C}}$
 $k = 0.430$

Part B: (examples taken from trial 2)

1) $\Delta k = k_n - k_{n+1}$
 $\Delta k = k_2 - k_1$
 $\Delta k = 1004.04 - 1008.90$
 $\Delta k = -4.66$

2) $k = PV$
 $k = (111.56)(9)$
 $k = 1004.04$

Discussion:

Part A:

The verification of Charles' Law in the lab was successful and clearly demonstrates the mathematical relationship, $V=kT$. The easiest way to measure this value in the lab and eliminate some experimental and human error is to use ΔV and $|\Delta T|$. The following chart displays the findings of the experiment.

Trial	V _{1gas}	ΔV	V _{2gas}	T ₁	T ₂	ΔT	k = ΔV/ΔT
1	150mL	49.2mL	100.8mL	101.2°C	14.1°C	87.1°C	0.560
2		39.9mL	110.1mL	101.3°C	8.0°C	93.3°C	0.430
3		31.3mL	118.7mL	103.5°C	15.9°C	87.6°C	0.360

The k values appear to vary by as much as 0.2 which yields an experimental error of 35.7%. However, these discrepancies should be attributed to several errors experienced during the lab.

The primary reason for the discrepancy is due to a human error obtained during the first trial which was caused when the student misstepped and potentially managed to scoop water into the flask while trying to regain her balance. For this reason, trial one should be overlooked. That brings the experimental error into a much more reasonable 16.3%. This error is likely due to several other smaller experimental sources of error, including the lack of an airtight seal on the open top of the Erlenmeyer flask.

Furthermore, the water volumes in the ice bath were an uncontrolled variable which may have affected the time needed to cool the flask since larger volumes of water at the same temperature would absorb more kinetic energy from the submerged flask, decreasing the amount of time required to cool the flask.

Another variable that was not controlled was the time that the flask spent submerged in the ice bath which could have affected the final temperature of the gas immediately before the seal was released and the water was sucked into the flask. This would result in deviations from the measured T₂ values and the actual T₂ values.

Outside of lab conditions Charles' Law can be observed in several day to day situations such as when hot food is sealed in a flexible container and placed in the fridge. When it is next removed from the fridge, the air, which had been heated up by the food, will have cooled and compressed, forcing the flexible container walls to curve inwards to accommodate for the decreased volume of its contents. Another example is heat canning in which the contents of an inflexible container are heated, sealed, and then rapidly cooled in order to create an airtight seal between the lid and the container.

Part B:

The data collected from the verification of Boyle's Law aligned itself well with his equation: $PV = k$. His law states that any constant amount of gas molecules at a constant temperature will have the same value for any volume of container multiplied by the resulting pressure within the container. The experiment results found the following:

	Trial 1			Trial 2			Trial 3		
P is measured in kPa, V is measured in mL									
	PV =	k	Δk	PV =	k	Δk	PV =	k	Δk
1	(100.89)(10) =	1008.90	original	(100.94)(10) =	1009.40	original	(100.87)(10) =	1008.70	original

2	(111.56)(9) =	1004.04	-4.66	(110.91)(9) =	998.19	-10.81	(110.94)(9) =	998.46	-10.24
3	(125.27)(8) =	1002.16	-1.88	(123.91)(8) =	991.28	-6.91	(124.80)(8) =	998.40	-0.06
4	(141.48)(7) =	990.36	-11.80	(140.39)(7) =	982.73	-8.55	(141.87)(7) =	993.09	-5.31
5	(160.98)(6) =	965.88	-24.48	(161.69)(6) =	970.14	-12.59	(161.75)(6) =	970.50	-22.59
6	(190.64)(5) =	953.20	-12.68	(190.77)(5) =	953.85	-16.29	(191.54)(5) =	957.70	-12.80
7	(100.87)(10) =	1008.70	+55.50	(99.20)(10) =	992.00	+38.15	(98.17)(10) =	981.70	+24.00
	Δk from 1 - 6		-55.70	Δk from 1 - 6		-55.55	Δk from 1 - 6		-51.00
	Δk from 1 - 7		-0.2000	Δk from 1 - 7		-17.40	Δk from 1 - 7		-27.00

The data obtained appears at first to have a constant decrease in the k value as the volume is decreased. However, the consistency in the value of Δk from 1-6 shows that all three trials experienced very similar decreases. Upon further analysis of the procedure it became evident why the decrease may have occurred. First of all, the gas within the syringe is a real gas and not an ideal gas which means that the particles do have mass and do exert forces on one another. As such, variations from the predictions of the Ideal Gas Law and all associated laws should be expected to some degree. Beyond which, the seal between the GPS and the syringe end was not air tight and a perfectly sealed container was never achieved. As the pressure mounted and the container became smaller, gas may have escaped out of the container, resulting in less than 10mL of gas being compressed.

Furthermore, the syringe volume graduations only allowed for the volume to be read to the nearest mL and the pressure reading never fully stabilized due to the inability for the student to hold her hands steady enough. All of these potential sources of error can account for the average loss of between 51.00 and 55.55 from the constant k.

The theory of these errors is further supported by the fact that the second reading of pressure of 10mL of gas in a 10mL container is always less than the first reading which supports the idea that less gas is inside the syringe at the end of the trial than at the beginning.

An example of this gas law outside of lab conditions includes the natural atmosphere of Earth. As gas approaches the Earth's core the pressure increases and the volume the air occupies decreases. Near the edge of the Earth's atmosphere smaller volumes of air occupy larger spaces at lower pressures. Ergo, the findings of the experiment align well with the expected results and verify Boyle's Law.

Conclusion:

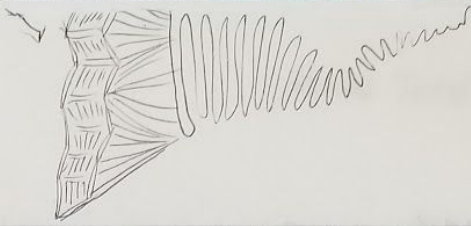
The lab results obtained were consistent with Charles' and Boyle's Law. For Charles' Law, the values obtained for the k constant were 0.430, and 0.360 (an average of 0.395), with an experimental error of 16.3%. For Boyle's Law, the results as the volume of air in the syringe decreased from 10ml to 5ml was -55.70 kPa, -55.55 kPa, -51.00 kPa (average of 54.1 kPa), with an experimental error of 8.2%.

References:

Benson, T. (2015, May 5). Animated Charles and Gay-Lussac's Law. Retrieved from <https://www.grc.nasa.gov/www/k-12/airplane/aglussac.html>

Hall, N. (Ed.). (2015, May 5). Boyle's Law. Retrieved from <https://www.grc.nasa.gov/www/k-12/airplane/boyle.html>

Raw Data Notes:



Experiment 1

VS

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★ Qualitative vs Quantitative data.

How change in temperature changes volume of gas in E. Flavr.

★ Print out Lab safety Agreement (Appendix)

A) Charles' Law

Temp & Volume
↑ dependent
↑ independent

T1 (temperature after 67 mins boiling): 101°C

Boil: 3:50 4:01
Transfer to ice bath: 3:57 4:09

trial: 4.16

★ dependent vs independent variables

Ice bath: 14°C

C.L.I.

Water collected in E. Flavr: 49.2 mL

Dependent variable: Volume of water in the E. Flavr
Independent variable: Temperature change
Controlled variable: Temperature of surrounding (room temp), Pressure

	Trial 1	Trial 2
Boiling temp:	101.2°C	101.3°C
Ice bath temp:	14.0°C	8.0°C
Water Volume:	49.2 mL	39.9 mL

How change in pressure changes volume of gas in syringe.	Trial 3	Trial 1	Trial 1	Trial 2	Trial 3
Boiling Temp:	103.5°C	5:10	100.75 kPa	100.81 kPa	
Ice Bath Temp:	15.3°C	5:16	124.75 kPa	126.16 kPa	
Water Volume:	31.3 mL	10 mL container	158.47 kPa	164.33 kPa	
		8 mL	223.47 kPa	225.52 kPa	
		6 mL	229.55 kPa		
		4 mL	225.46 kPa		
		2 mL	103.26 kPa		
		3 mL			
		10 mL			

B) Boyle's Law
pressure & volume

Dependent variable: Pressure
Independent variable: Volume of container
Controlled variable: Temperature, volume of gas = 10 mL

→ reads on the back.

★ Refer to picture for procedure ★

~~Volume~~ ~~Bar 1~~ ~~Bar 2~~

Volume (ml)	Trial 1 Pressure (kPa)	Trial 2 (kPa)	Trial 3 (kPa)
10 ml	100.87	100.94	100.87
9 ml	111.56	110.91	110.14
8 ml	129.27	123.91	124.82
7 ml	144.48	140.39	144.87
6 ml	160.88	161.69	161.75
5 ml	180.64	180.77	181.54
10 ml	101.97	99.80	98.17

√3

CHM 1311 LAB - Section 2

Lab One - Charles' and Boyles' Laws - Sept 18, 18

Lab TA: Vanessa - vsuse027@uottawa.ca

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Lab coordinators: Rashmi - vrashmi@uottawa.ca

Wendy - wendy.pell@uottawa.ca

✓

Procedure for Boyle's Law

1. set up the Gas Pressure Sensor ^(GPS) using dependant variable of pressure and an independant variable of volume.
2. collect 5 mL of gas in the 20 mL syringe and attach to GPS
3. set up LabQuest 2 data-collection mode record values for gas in original container size
4. restrict the volume of gas into $\frac{2}{3}$ of the original container size and record values
5. restrict the volume of gas into $\frac{1}{2}$ of the original container size and record values
6. Repeat steps 2-5 using 10 mL, 15 mL, and 20 mL respectively.

Revised Procedure for Boyle's Law

1. set up the Gas Pressure Sensor (GPS) dependant variable: pressure
independant variable: volume
2. collect 10 mL of gas in the 20 mL syringe and attach to GPS
3. set up LabQuest 2 data collection mode
4. record values for gas in a 10 mL, ⁹9 mL, ⁸8 mL, ⁷7 mL, ⁶6 mL, ⁵5 mL, ~~4 mL~~, ~~3 mL~~, ~~2 mL~~, ~~1 mL~~ and 4 mL containers respectively
5. return container to a 10 mL volume and record values

VS

DATE / /

Data for Verification of Charles' Law

<u>Trial 1</u>	<u>Trial 2</u>	<u>Trial 3</u>
Boiling Temp: 101.2°C	101.3°C	103.8°C
Ice Bath Temp: 14.1°C	8.0°C	15.9°C
Water Collected: 49.2 mL	39.9 mL	31.3 mL

Variables

independant: temperature change

dependant: volume of water collected

controlled: 150 mL gas in Erlenmyer flask, room temp, pressure = 1 atm,

Data for Verification of Boyles' Law

Trial 1	<u>Trial 1</u>	<u>Trial 2</u>	<u>Variables</u> independant: ^{volume} pressure container dependant: pressure controlled: volume gas = 10 mL, room temp,
10 mL container	100.75 kPa	100.81 kPa	
8 mL container	124.75 kPa	126.16	
6 mL container	158.47 kPa	164.33	
4 mL container	223.97 kPa	225.52	
2 mL container	223.55 kPa		
3 mL container	225.46 kPa		
10 mL container	103.26 kPa		

	<u>Trial 1</u>	<u>Trial 2</u>	<u>Trial 3</u>
10 mL	100.89 kPa	100.94 kPa	100.87 kPa
9 mL	111.56 kPa	110.91 kPa	110.94 kPa
8 mL	125.27 kPa	123.91 kPa	124.80 kPa
7 mL	141.48 kPa	140.39 kPa	141.87 kPa
6 mL	160.98 kPa	161.69 kPa	161.75 kPa
5 mL	190.64 kPa	190.77 kPa	191.54 kPa
10 mL	100.87 kPa	99.20 kPa	98.17 kPa

Peer Evaluations:

COURSE: CHM 1311 TA Name: Vanessa ~~Stasi~~ Suscovski
YOUR NAME (PRINT): Rose Silvestru SIGNATURE: Rose
~~Daryna Kucherenko~~

CONFIDENTIAL PEER EVALUATION FORM FOR EXPERIMENT _____
Each team member must submit one assessment form evaluating each other member of the team.
Teams may consist of 2-3 members for reports and up to 18 for planning sessions.
You may edit this form.
Do not share or discuss the contents or possible contents of this assessment with others.


In assessing the work of your fellow team members, consider the following aspects:

- Quality of work
- Contribution to the work as a whole
- Ability to get along with others
- Improvements when asked to correct

Team member name	Comments	Grade
Daryna Kucherenko	.worked well .split work 50/50 with me	100% A Excellent 5

Course: CHM 1311 TA: Vanessa Susevski

Your Name: Daryna Kucherenko

Signature: 

Team Member Name: Rose Silivestru

Comments: - worked efficiently and hard.
- split work evenly & did not
slack off ;)

Grade: 100%

A- ~~EX~~cellent (5)