

VERIFICATION OF GAS LAWS

By:

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Introduction:

Gases do not behave like the other forms of matter. A sample of gas fills a container as its particles are spread far apart, randomly arranged, and in constant motion. The lack of fixed volume and shape of gas can be explained by its weak intermolecular forces between particles. There are four variables that describe the physical behavior of an ideal gas: pressure (P), temperature (T), volume (V), and amount (number of moles, n); these variables are interdependent: “any one of them can be determined by measuring the other three” (Silberberg and Amateis, 173). However, gases need to behave ideally in order to be examined. Some gases show nearly ideal behavior, but such gas does not exist, which is why assumptions are made when experimenting. The ideal gas law equation is an approximation used to predict and to examine the behavior of real gases; the four variables that describe the physical behavior of gas is related to R, the gas constant.

$$PV = nRT \quad [1]$$

P = pressure (kPa)
V = volume (mL)
n = amount (number of moles)
T = temperature (K)
R = 0.082057 L • atm / (mol • K)

In the laboratory experiment, we examined the interdependence of the four variables that describe the physical behaviour of gas, in which we expected to form a linear relationship.

We attempted to verify that the relationship between the volume of a sample of gas is directly proportional to temperature, at which the external pressure and amount are constant. Based on the volume-temperature relationship described by Charles' Law [2], we measured the behavior of a sample of gas in a container submerged in a boiling water bath, and in an ice water bath. The independent variable, temperature (K) of each water bath, was directly manipulated with the use of a hot plate, and ice. A thermometer (°C) was used to monitor the temperature of the water baths. The temperature recorded in the experiment was converted from Celsius to Kelvin, the absolute scale for temperature. The dependent variable, volume (ml), was measured with an Erlenmeyer flask.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad [2]$$

In part 2, we examined Boyle's Law [3], the inversely proportional relationship between pressure-volume by exerting different rates of pressure at a constant temperature. The product of pressure and volume, at a constant temperature, determined by Boyle's law constant (k), [4] was measured with the data obtained from the experimental variables. The dependent variable, volume (mL), was directly controlled through a 20 mL plastic syringe connected to a Gas Pressure Sensor. The independent variable, pressure (kPa), was recorded through the Vernier LabQuest 2. This software was used to record and to analyze the data obtained from the experiment. Temperature and amount remained constant throughout the experiment

$$P_1V_1 = P_2V_2 \quad [3]$$

$$PV = k \quad [4]$$

Procedure:

Part 1: Charles' Law — Volume-Temperature:

Reference CHM1311 "Experiment 1 Theory and Instructions" by Dr. Rashmi, pages 6-8 for materials and procedure.

Part 2: Boyle's Law — Volume-Pressure:

Reference CHM1311 "Experiment 1 Theory and Instructions" by Dr. Rashmi, pages 6, 8-10 for materials and Vernier LabQuest 2 procedure.

First, the variables of the experiment were identified and determined their units of measurement. The independent variable as volume in mL, and the dependent variable being measured as pressure in kPa. The plunger of the 20 mL plastic syringe was moved to an initial volume of 10 mL. In order to measure the pressure inside the plastic syringe, a Gas Pressure Sensor and Vernier LabQuest2 were used. Then, the measurements of the pressure inside the syringe were taken at 6 different volumes, at a rate of 1 mL. The plunger was moved back to the initial volume of 10 mL for a final measurement. The data was organized into a table After observing the table of volume-pressure, it was decided that the first measurement for the initial mark of 10 mL was going to be kept. 0.8 mL was added to each of the volume readings, which is the volume inside the Gas Pressure Sensor.

Data, Observations and Results:

Part 1: Charles' Law — Volume- Temperature:

Trial 1:

$$T_1 = 375.15 \text{ K} \quad T_2 = 278.15 \text{ K}$$

$$V_1 = 148 \text{ ml} \quad V_2 = 109 \text{ ml}$$

$$V_{cw} = 39 \text{ ml}$$

$$\text{Percent error} = 0.668 \%$$

Trial 2:

The procedure for part 1 of the experiment was being completed, as the Erlenmeyer flask was being submerged into the ice water bath. However, when entirely submerged, air bubbles (gas) escaped the flask, it would not be possible to verify Charles' Law with the data from the experiment. Therefore, the experiment was stopped. It would not be possible to conduct another trial as there was no dry and clean flask available, and the remaining time for the laboratory was not sufficient.

- When steps 8 and 9 of the lab manual procedure were being completed, a suction was noticed when the finger was removed from the rubber stopper.
- As the Erlenmeyer flask was submerged into ice water for 5-6 minutes in order for the temperature of the water to equilibrate, minimal amount water was entering the flask.
- It was not possible to submerge the Erlenmeyer flask to the rim in the boiling water as suggested by the procedure, but that did not end up affecting the quality of results.
- The internal temperature of the flask could not be taken as the thermometer did not fit in the hole that the stopper had.

Part 2: Boyle's Law — Volume-Pressure:

Table 1: Volume-Pressure experimental.

Trial 1		Trial 2	
Volume (mL)	Pressure (kPa)	Volume (mL)	Pressure (kPa)
10.8	101.96	12.8	101.85
9.8	113.48	11.8	110.36
8.8	127.10	10.8	119.92
7.8	143.03	9.8	133.03
6.8	164.85	8.8	148.46
5.8	189.96	7.8	164.15

4.8	225.80	6.8	184.07
10.8	102.87	12.8	102.91

Trial 1: Volume-Pressure

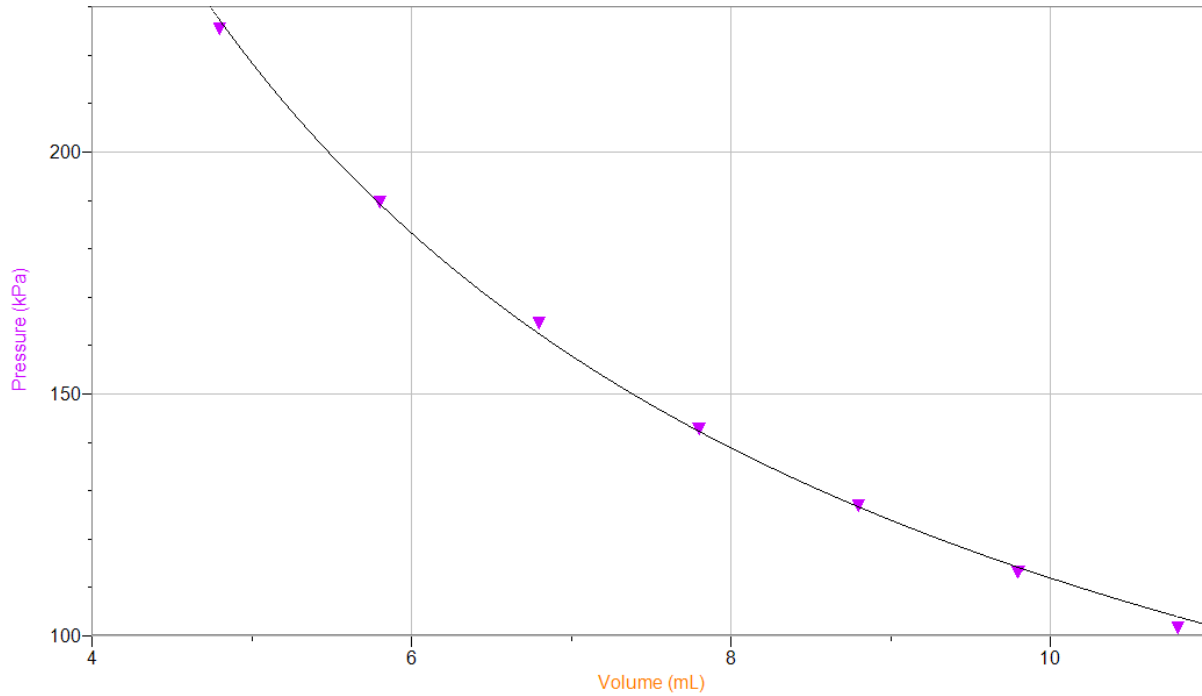


Figure 1: Relationship between volume of 20ml plastic syringe and pressure exerted.

Table 2: Trial 1 – General equation of Figure 1.

Power Function
$f(x) = a x^b$
a = 1031
b = -0.9642
Correlation: 0.999419
RMSE: 1.65168

Trial 2: Volume-Pressure

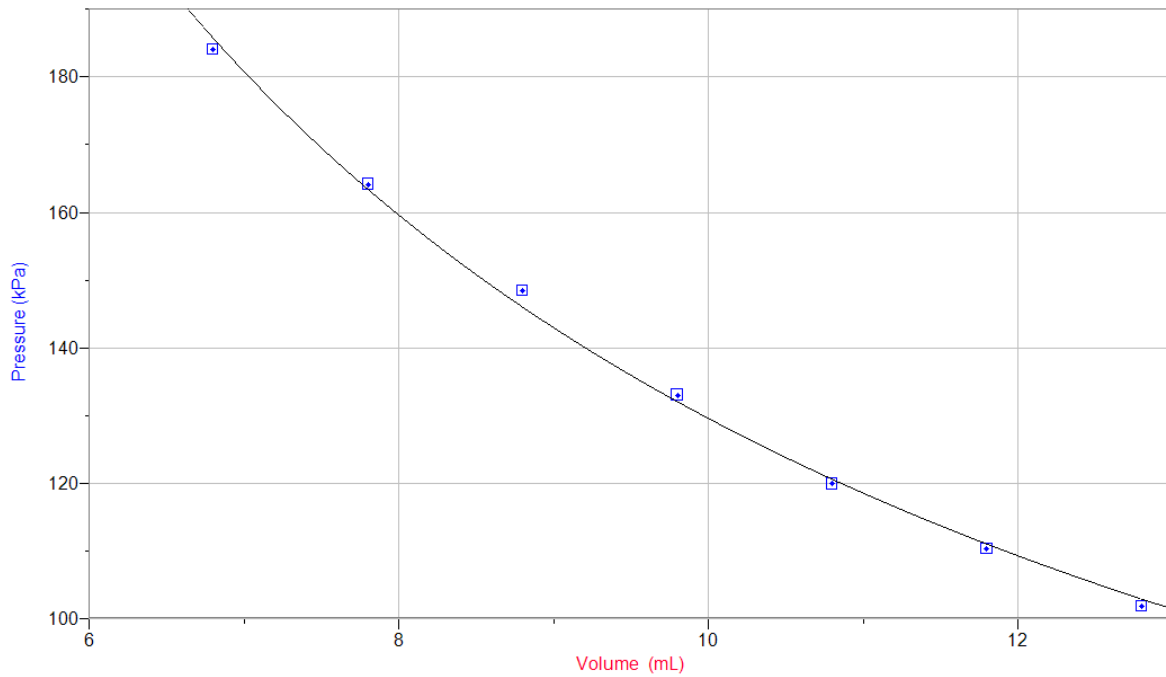


Figure 2: Relationship between volume of 20ml plastic syringe and pressure exerted.

Table 3: Trial 2 – General equation of Figure 2.

Power Function
$f(x) = a x^b$
a = 1112
b = - 0.9336
Correlation: 0.998846
RMSE: 1.56909

- In both trials 1 and 2, it was observed that when the plunger of the 20 mL plastic syringe was moved to decreasing volumes, it became harder to push it.
- Instead of performing a series of trials with the same value, two trials of different volume measurements were done.
- Figure 1 and Figure 2 shows that the relationship between the volume (ml) in the plastic syringe and pressure (kPa) is inversely proportional.
- In Table 2 and Table 3, the coefficients 0.999419 and 0.998846 shows a strong relationship between the volume of the plastic syringe and the pressure inside it.

- The initial volume measurements taken in both trials, of 101.96 kPa and 101.85 kPa, were closer to atmospheric pressure of 101.32 kPa than the last measurements.
- Table 2 and Table 3 values do not correspond entirely to the data written on the notebooks. The data in the notebook is based on the graphs from Vernier LabQuest 2, in which the x-axis of the graph was “Pressure (kPa)” and the y-axis was “Volume (mL)”. After the data was transferred to LoggerPro, the graphs were examined, and it was decided that it would be better to have the x-axis as “Volume (mL)”, since it is the dependent variable, and the y-axis as “Pressure (kPa)”. The data plotted on the graph is the same.

Calculations:

Part 1: Charles’ Law — Pressure-Temperature:

Converting from Celsius to Kelvin

$$T_1 = 102\text{ }^\circ\text{C}$$

$$T_1(\text{K}) = 102^\circ\text{C} + 273.15 = 375.15\text{ K} = 375\text{ K}$$

$$T_2 = 5\text{ }^\circ\text{C}$$

$$T_2(\text{K}) = 5^\circ\text{C} + 273.15 = 278.15\text{ K} = 278\text{ K}$$

Solving for V_2 , volume of gas, at T_2 (temperature of ice bath)

$$V_2 = V_1 - V_{\text{cw}}$$

$$V_2 = 148.0\text{ mL} - 39.0\text{ mL}$$

$$V_2 = 109\text{ mL}$$

Verifying Charles’ Law:

$$T_1 = 375\text{ K} \quad T_2 = 278\text{ K}$$

$$V_1 = 148\text{ ml}$$

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

$$\frac{148\text{ ml}}{375.15\text{ K}} = \frac{V_2}{278.15\text{ K}}$$

$$V_2 = (278.15\text{ K}) \left(\frac{148\text{ ml}}{375.15\text{ K}} \right)$$

$$V_2 = 278.15 \times 0.394\text{ ml}$$

$$V_2 = 109.7\text{ ml}$$

$$V_2 = 109\text{ ml}$$

Calculating the percent error:

$$\frac{\frac{V_1}{T_1} - \frac{V_2}{T_2}}{\frac{V_1}{T_1}} \times 100\%$$

$$\frac{\frac{148 \text{ ml}}{375.15 \text{ K}} - \frac{109 \text{ ml}}{278.15 \text{ K}}}{\frac{148 \text{ ml}}{375.15 \text{ K}}} \times 100\%$$

$$\frac{0.00256339755}{\frac{148 \text{ ml}}{375.15 \text{ K}}} \times 100\% = \frac{0.0025803357}{0.3945088631} \times 100\% = 0.0066765939$$

Percent error = 0.668 %

Part 2: Boyle's Law — Volume-Pressure

Calculating Boyle's law constant:

Trial 1:

$$P = 225.80 \text{ kPa}$$

$$V = 4.800 \text{ ml}$$

$$k (\text{constant}) = P \times V$$

$$k = (225.80 \text{ kPa}) \times (4.800 \text{ ml})$$

$$k = 1083.84 \text{ kPa} \cdot \text{mL}$$

$$k = 1084 \text{ kPa} \cdot \text{mL}$$

Trial 2:

$$P = 184.07 \text{ kPa}$$

$$V = 6.800 \text{ mL}$$

$$k (\text{constant}) = P \times V$$

$$k = (184.07 \text{ kPa}) \times (6.800 \text{ mL})$$

$$k = 1251.676 \text{ kPa} \cdot \text{mL}$$

$$k = 1252 \text{ kPa} \cdot \text{mL}$$

Calculating Boyle's Law constant average:

Trial 1:

$$\text{Average constant} = \frac{\text{sum of } k \text{ values}}{\text{number of } k \text{ values}}$$

$$\text{Avg. } k = \frac{PV_1 + PV_2 + PV_3 + PV_4 + PV_5 + PV_6 + PV_7}{7}$$

Avg. K

$$= \frac{(101.96 \text{ kPa} \times 10.8 \text{ ml}) + (113.48 \text{ kPa} \times 9.8 \text{ ml}) + (127.10 \text{ kPa} \times 8.8 \text{ ml}) + (143.03 \text{ kPa} \times 7.8 \text{ ml}) + (164.85 \text{ kPa} \times 6.8 \text{ ml}) + (189.96 \text{ kPa} \times 5.8 \text{ ml}) + (225.80 \text{ kPa} \times 4.8 \text{ ml})}{7}$$

$$\text{Avg. } k = \frac{1101.168 + 1112.104 + 1118.48 + 1115.634 + 1120.98 + 1101.768 + 1083.84}{7}$$

$$\text{Avg. } k = \frac{7753.974}{7}$$

$$\text{Avg } k = 1107.710571$$

$$\text{Avg } k = 1000$$

Trial 2:

$$\text{Avg. } k = \frac{PV_1 + PV_2 + PV_3 + PV_4 + PV_5 + PV_6 + PV_7}{7}$$

Avg. K

$$= \frac{(101.85 \text{ kPa} \times 12.8 \text{ ml}) + (110.36 \text{ kPa} \times 11.8 \text{ ml}) + (119.92 \text{ kPa} \times 10.8 \text{ ml}) + (133.03 \text{ kPa} \times 9.8 \text{ ml}) + (148.46 \text{ kPa} \times 8.8 \text{ ml}) + (164.15 \text{ kPa} \times 7.8 \text{ ml}) + (184.07 \text{ kPa} \times 6.8 \text{ ml})}{7}$$

$$\text{Avg. } k = \frac{1303.68 + 1302.248 + 1295.136 + 1303.694 + 1306.448 + 1280.37 + 1251.676}{7}$$

$$\text{Avg. } k = \frac{9043.252}{7}$$

$$\text{Avg } k = 1291.893143$$

$$\text{Avg } k = 1000$$

Discussion:

After performing part 1 and 2 of this experiment, we were able to confirm both Charles' Law and Boyle's Law with minimal error. During the Charles' Law experiment, the relationship between volume and temperature at constant pressure and amount was verified. We observed that as the temperature decreased when putting the Erlenmeyer flask into the ice water, the volume of the gas did as well. This is because the particles contract as the temperature cools and vice versa when the temperature increases. The experimental value of V_2 was nearly identical to the value that was expected through theoretical calculations, being only 0.7 mL apart. Error can be as a result of imprecise measuring tools. The graduated cylinder used to measure the volume for the V_{cw} and V_1 lack perfect accuracy, as well as the thermometer used to measure the temperature of the water

in this experiment. Atmospheric pressure was not measured throughout the experiment, so it is only assumed that the pressure did not change and the amount of gas in the flask remained constant. With only 0.668% error however, the results from the first trial are reliable. The experiment could have been improved if there were more accurate measuring equipment available to students in order to assure that variables remain constant.

After performing the Boyle's Law experiment in 2 separate trials, we proved that the relationship between volume and pressure was inversely proportional at constant temperature and amount. To ensure the amount stayed the same, we secured the syringe to the monitor, so no gas escaped, but it is impossible to know if any did or not which can contribute to error. Nothing could be done to ensure the temperature was constant as so it is assumed room temperature would not change. The results found are as expected, as the volume decreased, the pressure increased. The relationship was not linear as we originally predicted but a power function relationship instead, which makes sense as the equation $PV = nRT$ can be rearranged to form a power function equation. The random constant calculated for trial 1 was 1084 kPa•mL and the average for that trial was 1108 kPa•mL. The equation that describes the relationship illustrated by Boyle's law and the values for k in trial 1 is $1084 = PV$, and in trial 2 it is $1108 = PV$. These equations represent the constant value for the sets of data. In trial 2, 1252 kPa•mL was the random constant and 1292kPa•mL was the average constant. Since the number of moles changed from one trial to the next, so did the constant value. Both the random and average k value in each trial are close to one another, supporting the idea that it is a constant value when temperature and amount are kept constant as well. Error in the Boyle's Law experiment can arise from defective technology such as the pressure monitor, which had many fluctuations in pressure readings. It was noted that as the pressure in the syringe increased it was significantly harder to hold a steady volume when recording pressure which can impact some results. It was originally planned to start at a 20 mL volume and decrease by 2 mL each time, but we found out that the increased pressure would make it very hard to push the syringe to lower values. For this reason, two trials of this experiment were performed at lower start volumes in order to ensure the law could be proven with more ease. It is important to take two measurements of the dependent variable at the same original value of the independent variable because the first measurement may lack accuracy, so by taking another measurement it ensures the pressure was as close to the atmospheric pressure of 101.32 kPa the second time.

It can be noted that since the experiment did not provide as many trials as possible, as it would make the validation of both Charles' and Boyle's laws stronger, the experimental data, results, and observations made do support the objective of the laboratory, yet the results could be indeed more reliable and accurate with more trials.

Conclusion:

Based on the experimental data, observations, and results, Charles' Law and Boyle's Law are both validated. The relationship between pressure and volume, at a constant temperature and amount, described by Boyle's is verified through the relationship observed in the trials, at a constant rate of $1084 \text{ kPa} \cdot \text{mL}$, when $k = PV$. Charles' Law as the relationship between volume and temperature, at a constant pressure and amount, is verified by the percent error of 0.668%.

References:

Silberberg, Martin S. *Chemistry: The Molecular Nature of Matter and Change*. New York: McGraw-Hill, 2012.

Tenny, Kevin, and Cooper, Jeffrey. "Ideal Gas Behavior". *National Center for Biotechnology Information*. <https://www.ncbi.nlm.nih.gov/books/NBK441936/>.

Raw data: Jadde de Carvalho Tso

Locker 001 - TA Yiran Li
yli497@uottawa.ca.
September 19 2018
Boyle's law
Jadde de Carvalho Tso
September 25, 2018 YL

12

Independent: volume (mL³)
Dependent: pressure (atm) (kPa)

$PV = nRT$

Volume (mL ³)	Pressure (atm) (kPa)
20 mL ³ 10 mL ³	101.96 kPa / 102.87
18 mL ³ 9 mL ³	113.48 kPa
16 mL ³ 8 mL ³	127.10 kPa
14 mL ³ 7 mL ³	143.03 kPa
12 mL ³ 6 mL ³	164.85 kPa
10 mL ³ 5 mL ³	186.189.06 kPa
8 mL ³ 4 mL ³	225.80 kPa

Power $Ax^b = y$
 $A = 1031.5$
 $B = -0.9614$
 -0.9641
 RS RMSE = 1.396

Linear fit: $mx + b$
 $m = -20.08$
 $b = 808.93$
 $corr = -0.980$
 RMSE = 9.493

(add .8 to each volume reading)

Charles Lab

① boiling water (T) = 102°C (T₁)
 ice bath (T) = 5°C (T₂)
 $V_{cw} = 39 \text{ mL}^3$
 (T₂) V₂
 $V_1 = 148 \text{ mL}^3$

② boiling water T₁ = 103°C

gadi de Carvalho T&O
September 25, 2018

YL

② Boyle

Volume (mL)	Pressure (kPa)
12.8	101.85
11.8	110.36
10.8	119.92
9.8	133.03
8.8	148.46
7.8	164.15
6.8	184.07

Power

$$y = Ax^b$$

$$A = 1112.3$$

$$B = -0.93357$$

$$RMSE = 1.3261$$

Raw data: Hannah Perreault

Hannah Perreault
Sept 19, 2018

Boyle's Law

YL

Data:

Run 1:	Volume (mL)	Pressure (atm) ^{kPa}
	20 mL 10 mL	101.96 kPa or 102.87 kPa
	18 mL 9 mL	113.48 kPa
	16 mL 8 mL	127.10 kPa
	14 mL 7 mL	143.03 kPa
	12 mL 6 mL	164.85 kPa
	10 mL 5 mL	189.96 kPa
	8 mL 4 mL	225.80 kPa

~~Linear curve fit. $m: -20.08$ $b: 308.93$ $\text{coeff: } -0.98062$~~

Power curve fit. $A: 1031.5$ $B: -0.96418$ $\text{RMSE: } 9.493$
 $A \times B$ $\text{RMSE: } 1.396$

Charles's Law

Test 1: Temp. of water in hot bath: 102°C $\leftarrow T_1$
Temp. of water in ice bath: 5°C
Temp. of ice bath of submerge 6 min: 4°C $\leftarrow T_2$
 $V_{\text{cw}} = 39\text{ mL}$
 $V_1 = 50\text{ mL} + 50\text{ mL} + 48\text{ mL} = 148\text{ mL}$

Test 2: $T_1: 100^\circ\text{C}$ $T_2:$
 $V_1:$ $V_{\text{cw}}/V_2:$

Hannah Perreault
Sept 19, 2018

^{VL}
Boyle's Law

Run 2:

Volume (mL)

Pressure (kPa)

12 mL

101.85 kPa ~~102.91~~

11 mL

110.36 kPa

10 mL

119.92 kPa

9 mL

133.03 kPa

8 mL

148.46 kPa

7 mL

164.15 kPa

6 mL

184.07 kPa

Power curve fit: $y = Ax^B$

A: 1112.3 B: -0.93357

RMSE: 1.3261

Assessment Criteria for Planning the Boyle's Law Investigation
 (to be completed BEFORE lab and given to TA)

TA Name:	Yiran Li	Names of Students in Group:	a. Hannah Perreault
			b. Jaddle Tso
	Yiran	Date:	Sept. 19 th 2018
Criteria:	Marks Possible	Assessment	
		Self	TA
1. Identify the problem and state it clearly in a way that can be tested.	1		
2. Use proper apparatus, techniques and safety precautions.	1		
3. Materials are easily available.	1		
4. Plan to vary only one independent variable at a time.	1		
5. Controls on other variables are clearly stated.	1		
6. Measurement errors are minimized by appropriate procedures or apparatus.	1		
7. The methods are clear enough to be followed by other students.	1		
8. No invalid assumptions are made.	1		
9. Reagents that need accurate measurement are identified.	1		
10. Lab trials are stated.	1		
11. Repeats are stated.	1		
12. Chemistry vocabulary is used correctly.	1		
13. Limitations of the experimental design are described.	1		
TOTAL:	13	13	