

Experiment One: Verification of Boyle's Law

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Course: CHM1311 Section 5

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Introduction

The lab *Verification of Boyle's Law* tests the validity of Boyle's Law.

Boyle's Law was discovered experimentally by Robert Boyle in the seventeenth century. The law dictates that the pressure of a certain amount of a confined gas is inversely proportional to its volume. For example, doubling the pressure of a gas will halve the volume, and vice versa. This can be written as the following: $PV = k$.

There is a plethora of conditions that must be met for this law to hold true. Firstly, the temperature and the amount of gas must be the same. The ideal gas law, $PV = nRT$, where P is the pressure, V is the volume, n is the amount of gas, R is the proportionality constant, and T is the temperature, considers the amount of gas and temperature as factors that affect the property of the gas. The ideal gas law states that the pressure multiplied by its volume is proportional to the amount of gas multiplied by its temperature. In the case of Boyle's law, since n , R , and T are constants, the right side of the equation is a constant, which can simply be written as k , resulting in Boyle's law as stated above. The k value remains the same as long as the temperature and amount of gas stay the same. It is assumed for simplicity that the temperature and amount of gas remain constant throughout each trial.

Furthermore, Boyle's Law only pertains perfectly to ideal gases. An ideal gas is defined as a gas with infinitely-small molecules that do not exhibit intermolecular forces. Of course, such a gas is only theoretical. In a non-ideal gas, such as air, which was the gas used in this experiment, the particles themselves have volume, which is added to the volume predicted by the ideal gas law to form the actual volume, resulting in a slightly larger volume than predicted. In addition, the intermolecular attractions between gas particles, such as the London forces, attract the particles to each other, which slow them down. Consequently, the particles hit their container at a velocity that is lower than particles of an ideal gas would, reducing the pressure given a certain volume. In this lab, it is assumed, for simplicity, that the air used is an ideal gas. Although this assumption contains some error, the error is low because gas particles are very small and very far apart from each other.

Procedure

The following changes and additions were made to the procedure described in the lab handout "Verification of Boyle's Law," by Dr. Rashmi Venkateswaran:

1. Three trials will be done.
2. The syringe was set to have 10 mL of air inside for trials 1 and 3, while the volume was 5 mL for trial 2. Then it was screwed into the gas pressure sensor.
3. The volumes whose pressures were measured were 5.0 mL, 7.5 mL, 10.0 mL, 12.5 mL, 15.0 mL, 17.5 mL, and 20.0 mL for all trials.

Observations/Data/Results

Upon screwing the syringe on the gas pressure sensor, the pressure did not change. As one pressed or pulled on the plunger of the syringe, the bigger the pressure difference between what was shown on the display and the pressure of the room, the harder it was to physically maintain that pressure.

After letting go of the plunger, it moved within the syringe towards the volume it was set before being screwed in, until the difference in volume is small.

Table 1: Data and Results in the Verification of Boyle's Law

Trial #	Trial 1		Trial 2		Trial 3	
Volume and Pressure	Volume (mL)	Pressure (kPa)	Volume (mL)	Pressure (kPa)	Volume (mL)	Pressure (kPa)
	5.8	190.32	5.8	100.55	5.8	190.74
	8.3	130.64	8.3	68.10	8.3	131.42
	10.8	100.14	10.8	51.83	10.8	100.15
	13.3	80.00	13.3	41.42	13.3	80.15
	15.8	67.40	15.8	35.17	15.8	67.53
	18.3	57.60	18.3	30.41	18.3	61.08
	20.8	50.90	20.8	26.60	20.8	50.75
<i>k Value</i>	1106 Pa*L		572.2 Pa*L		1097 Pa*L	
<i>k_{average of Trials 1 and 3}</i>	1102 Pa*L					
<i>σ of k values of Trials 1 and 3</i>	4.50					

Calculations

Average k Value

$$k_{\text{average}} = (k_1 + k_2) / 2$$

$$k_{\text{average}} = (1106 \text{ Pa*L} + 1097 \text{ Pa*L}) / 2$$

$$k_{\text{average}} = 1102 \text{ Pa*L}$$

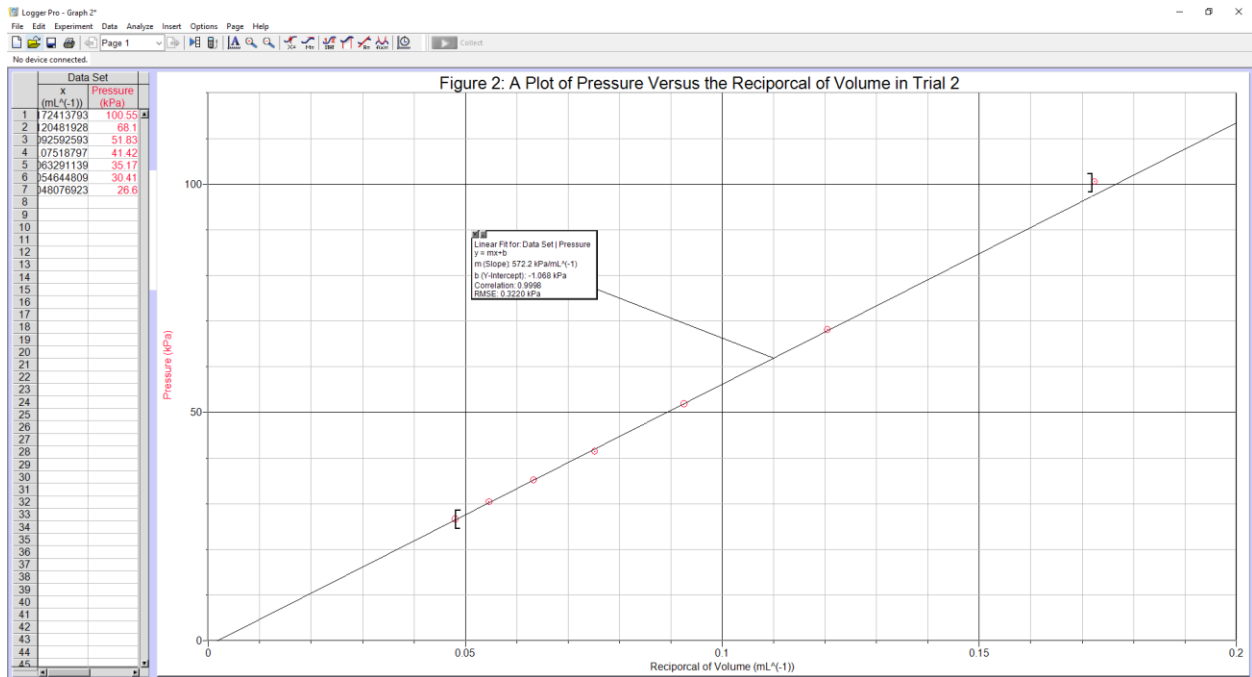
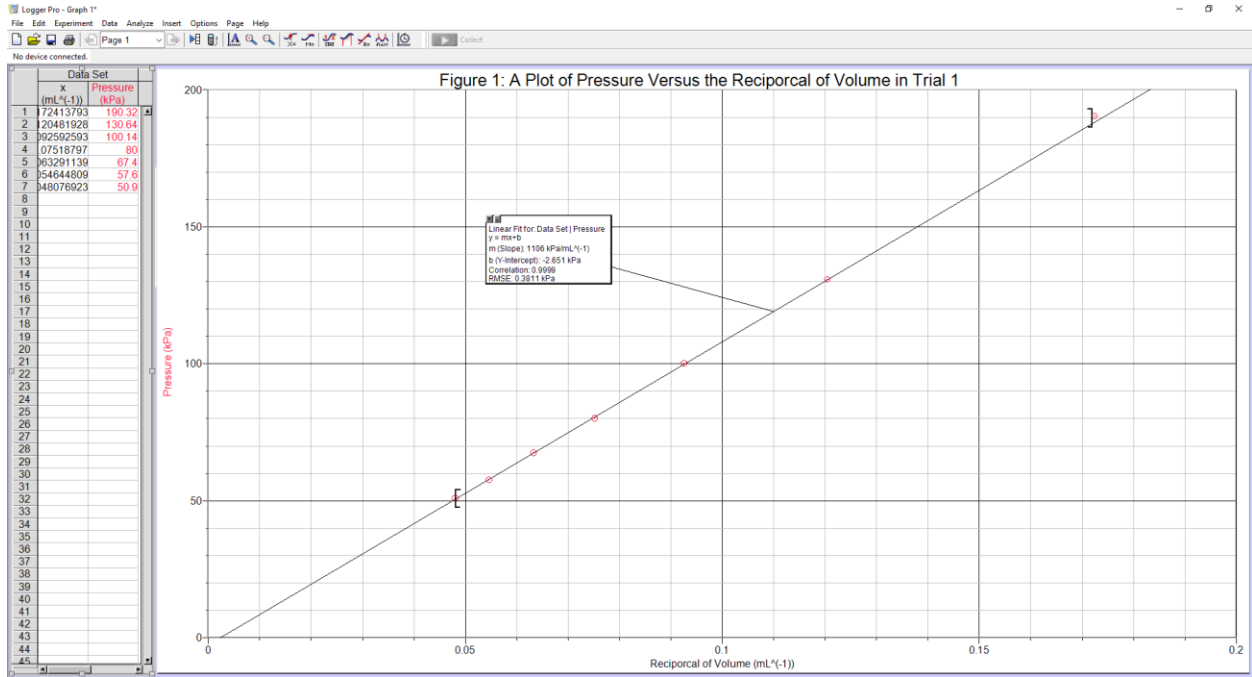
Standard Deviation

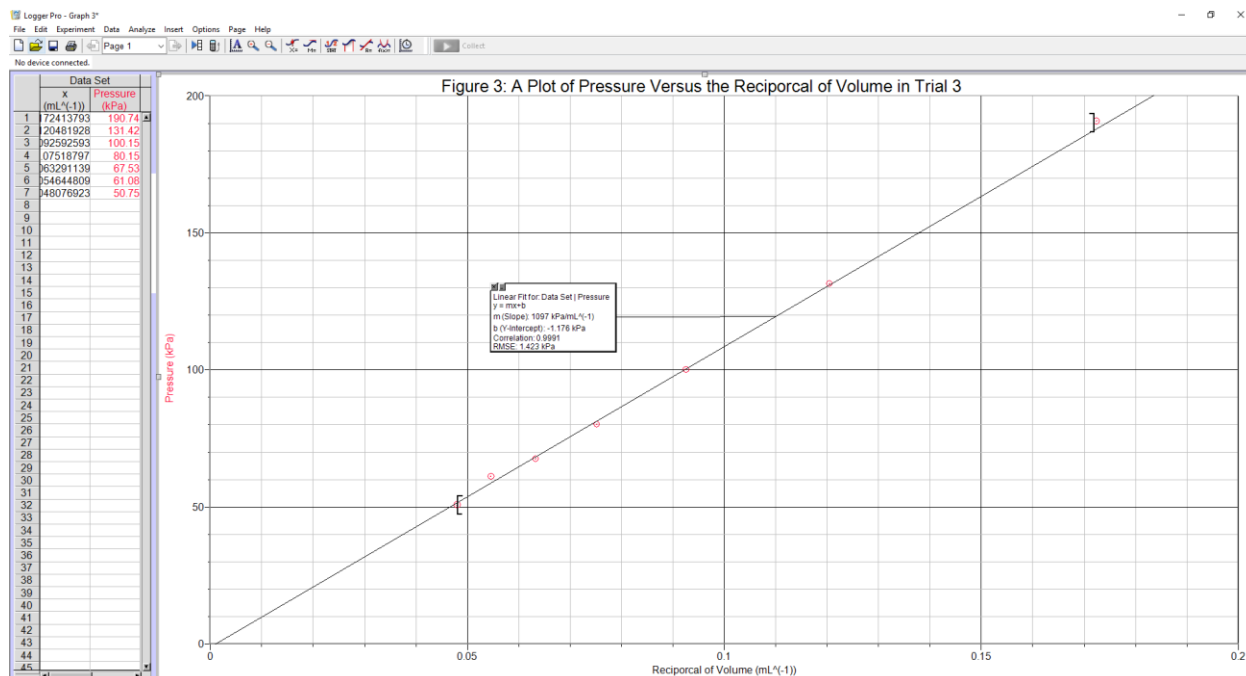
$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2}$$

$$\sigma = \sqrt{\frac{1}{2} [(1106 \text{ Pa*L} - 1102 \text{ Pa*L})^2 + (1097 \text{ Pa*L} - 1102 \text{ Pa*L})^2]}$$

$$\sigma = 4.50$$

Graphs





Discussion

Boyle's Law

The Boyle's Law Constant, k , is represented by the formula $PV = k$. It means that the pressure multiplied by the volume is a constant. Though one may simply multiply pressure and volume to obtain this constant for each data entry, the k value is instead calculated by Logger Pro. The k value is simply the slope of the graph if the graph P vs $1/V$ is graphed because $P = k * 1/V$. The constants for Boyle's Law are 1106 Pa*L, 572.2 Pa*L, and 1097 Pa*L, respectively, for Trials 1, 2, and 3. Therefore, the following equations can be written: $PV = 1106 \text{ Pa*L}$, $PV = 572.2 \text{ Pa*L}$, and $PV = 1097 \text{ Pa*L}$, respectively.

Boyle's Law requires several conditions to be met. As explained in the introduction, first, the amount of gas and the temperature must remain the same. For temperature, it is assumed that the temperature of the room remained consistent throughout the experiment. This assumption has very little error as the room is temperature-controlled, and contributes to make the experiment simpler. Even small differences, such as one of around 1 K, contribute little error because the room is around 300 K. As for keeping the amount of gas consistent, the air was sealed in the syringe and gas pressure sensor. The screw-on seal prevented air from escaping, though again, a small amount of gas may escape, contributing to some error. The error is insignificant because the screw in the apparatus is very air tight. No air was escaping when the plunger was pressed, and the pressure was not shifting towards 100 kPa when the plunger was held in place. The assumption that the amount of gas remains the same throughout each trial also adds simplicity to the experiment.

One could find out if there has been a significant change in the amount of gas if one took measurements of the initial volume once at the start and once at the end. Gas particles could leak in or out of the syringe during the experiment if it were not screwed on properly or if the syringe has malfunctioned. If the pressure of the starting volume differed significantly between the start and the end, then one can be sure that such an error has occurred. As a result, one may choose not to use this set of data as it may be inaccurate.

Other Sources of Error

There were other sources of error in this experiment. First, the barrel of the syringe is plastic, which is a flexible material, and it may expand or contract minutely, leading to error in its ability to indicate the correct volume, especially in higher pressures when expansion is the greatest.

Furthermore, the syringe has an uncertainty that contributes to error. The lines that mark the volumes on the syringe were thick, and so was the end of the plunger. As a result, even if the two lines line up for a particular volume, there is a lot of variation that can occur in the actual volume held in the syringe, and the real volume may be either too high or too low. This situation creates random error in the experiment.

Error Analysis

Since Trial 2 used a different starting volume, its k value could not be averaged with the k values of Trials 1 and 3. Thus, the average k value and the standard deviation pertains only to the data of Trials 1 and 3. The standard deviation was 4.50, which is a low number considering that the k values average to 1102 Pa*L.

The graphs provide not only the k values themselves, but also the correlation of the data. The correlation values for Figures 1, 2, and 3, are 0.9999, 0.9998, and 0.9991, respectively. These are very high correlations, indicating that there were very few random errors in this experiment. A different initial volume was chosen for Trial 2 was to ensure that Boyle's Law works for different amounts of gas as well. Since the correlation of Trial 2's data points is 0.9998, it is evident that Boyle's Law is validated for different amounts of gas.

However, significant systematic error can still exist, affecting all the data points equally such that the correlation still remains high. To calculate the significance of systematic errors, the right side of the Ideal Gas Law equation, nRT , can be calculated and compared with the k values obtained.

Conclusion

For the lab "Verification of Boyle's Law," the k values for Trials 1, 2, and 3 are 1106 Pa*L, 572.2 Pa*L, and 1097 Pa*L, respectively. The mean k value for Trials 1 and 3 is 1102 Pa*L, and the standard deviation of the k values of Trials 1 and 3 is 4.50.

References

Berry, G. S. (1986). Boyle's Law. *The Journal of Education*, 43(23), 382-383

McGraw-Hill Dictionary of Scientific and Technical Terms, 6th ed., McGraw-Hill, New York, 2003

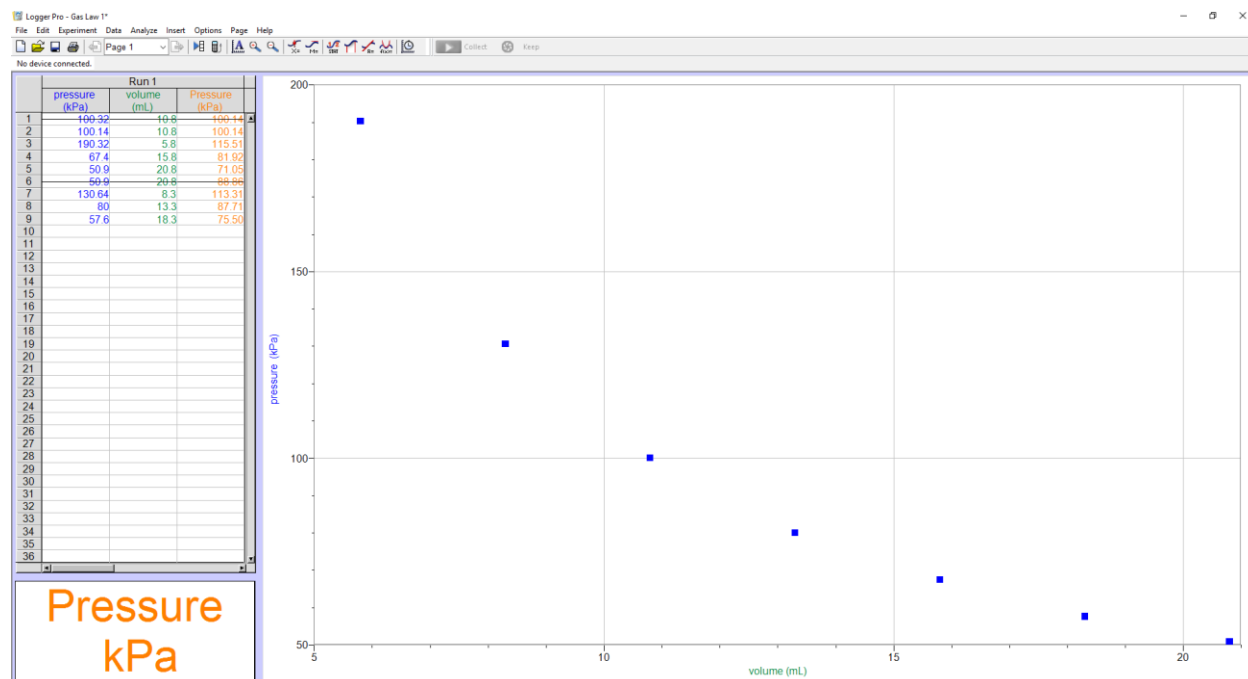
Non-ideal behavior of gases. (n.d.). Retrieved September 17, 2017, from <https://www.khanacademy.org/science/chemistry/gases-and-kinetic-molecular-theory/non-ideal-gas-behavior/a/non-ideal-behavior-of-gases>

Standard Deviation Formulas. (n.d.). Retrieved September 18, 2017, from <https://www.mathsisfun.com/data/standard-deviation-formulas.html>

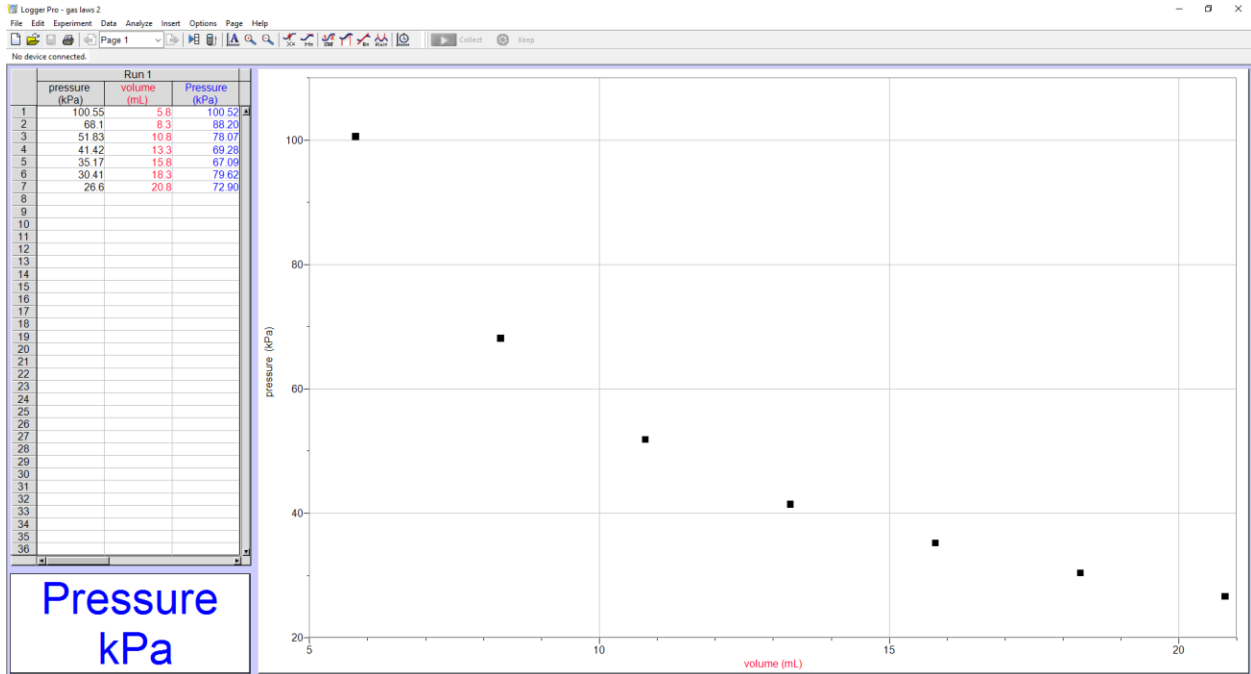
Raw Data

Logger Pro

Trial 1:

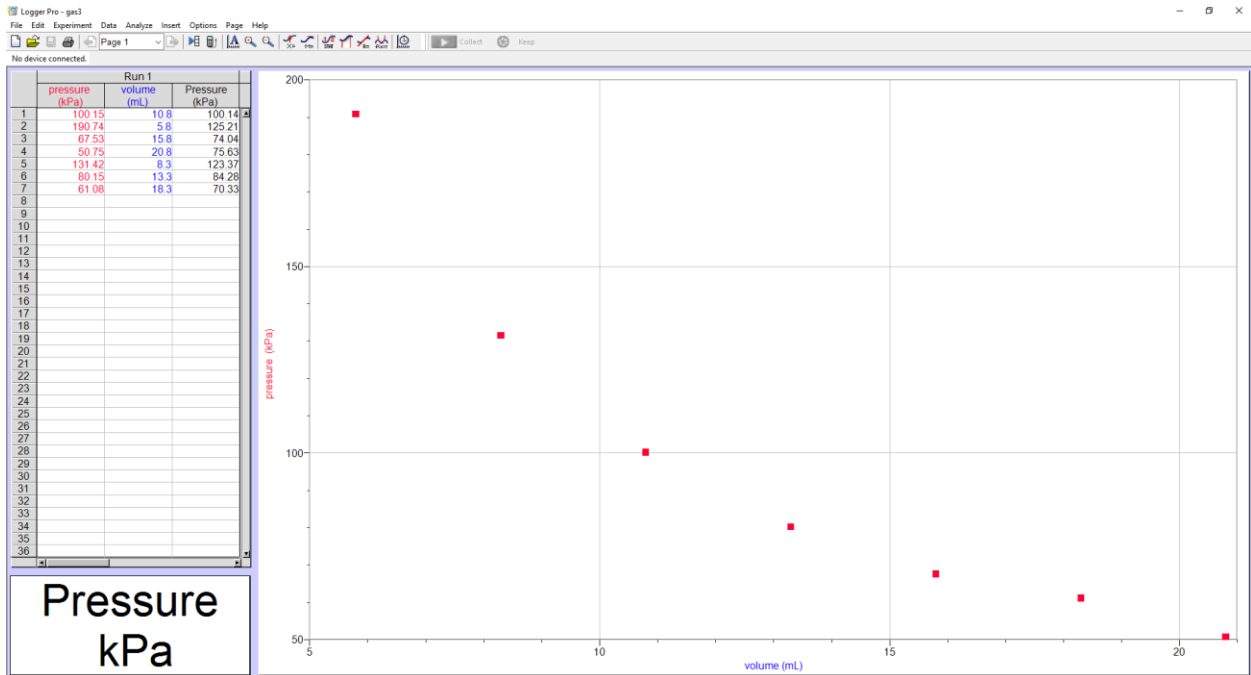


Trial 2:



Pressure
kPa

Trial 3:



Pressure
kPa

Lab Book Notes

Experiment 1

- dependent variable - pressure
- independent variable - volume

We decided because it is the volume ^{we} the control.

For lab counts!

Put Safety glasses ~~off~~ on. Warming - 0 on lab

No food or drink

Procedure

- Screw syringe onto sensor after starting the syringe at ~~10ml~~ 10ml
- Record the pressure when the gas is forced to be 20ml, 10ml, 15ml, 5ml. Reports if needed.

Add 0.8ml to each gas sensor.

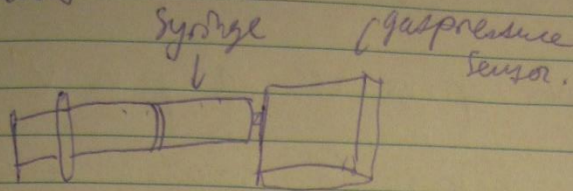
- Plot data on graph

$$pV = R$$

Table 1: Volume and Pressure of Air

Volume (ml)	Pressure (kPa)
Trial 1	
10.8	100.14
5.8	190.32
15.8	67.40
20.8	50.90
8.3	130.64
13.3	80.00
18.3	57.60
Trial 2	
5.8	100.55
8.3	68.10
10.8	51.83
13.3	41.42
15.8	35.17
18.3	30.41
20.8	26.60
Trial 3	
10.8	100.15
5.8	190.74
15.8	67.53
20.8	50.75
8.3	131.42
13.3	80.15
18.3	61.08

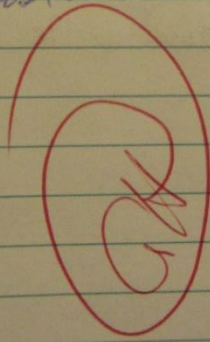
Apparatus



Limitations: - Syringe doesn't allow too much stretching.
(human muscle strength is limited)

- Syringe can stretch as well, changing the pressure given into the sensor.

Constants: everything else in the ideal gas law:
Temperature & amount of gas are kept constant



Assessment Criteria for Planning the Boyle's Law Investigation

TA Name: Greg Hodgson		Names of Students in Group:	a. Yu Jia (Danny) Ke
			b. Jacob Turner
		Date:	Sept 13, 2017
Criteria:	Marks	Assessment	
	Possible	Self	TA
1. Identify the problem and state it clearly in a way that can be tested.	1	1	
2. Use proper apparatus, techniques and safety precautions.	1	1	
3. Materials are easily available.	1	1	
4. Plan to vary only one independent variable at a time.	1	1	
5. Controls on other variables are clearly stated.	1	1	
6. Measurement errors are minimized by appropriate procedures or apparatus.	1	1	
7. The methods are clear enough to be followed by other students.	1	1	
8. No invalid assumptions are made.	1	1	
9. Reagents that need accurate measurement are identified.	1	1	
10. Lab trials are stated.	1	1	
11. Repeats are stated.	1	1	
12. Chemistry vocabulary is used correctly.	1	1	
13. Limitations of the experimental design are described.	1	1	
TOTAL:	13	13	
