Experiment:
Gases

I. INTRODUCTION

The primary objective of this experiment is to determine the relationship between the a) pressure and volume and b) the pressure and temperature of a confined gas. Historically, the relationship between pressure and volume was first established by Robert Boyle in 1662 and has since been known as **Boyle's law**. Nearly a century later, the connection between pressure and temperature was established by Joseph Gay-Lussac and the relationship is called **Gay-Lussac's law**. The results from this experiment will allow you to rediscover the same mathematical relationships described by Boyle and Gay-Lussac centuries ago.

Gases are made up of molecules that are in constant motion. Each collision of a gas molecule with the walls of its container exerts a force on the surface. The force per unit area is the **pressure** of the gas. Pressure measured with a mercury barometer is usually reported in **millimeters of mercury (mm Hg)**; a unit that is also called the **torr**. Another common unit of pressure is the **pascal (Pa)** or **kilopascal (kPa).** The relationship of all these units of pressure to a **standard atmosphere (atm)** is defined as

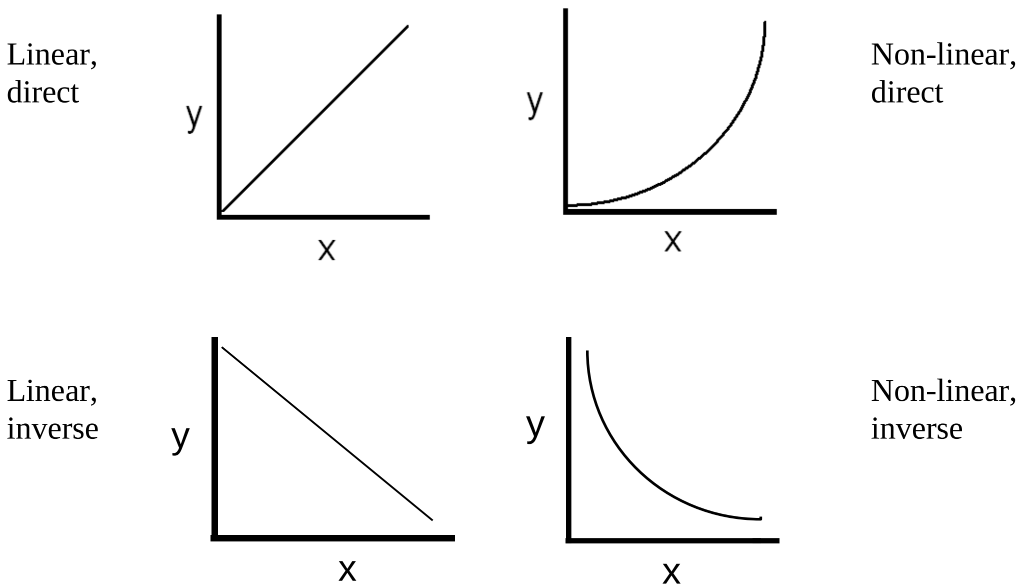
$$1 \text{ atm} = 760 \text{ mm Hg} = 760 \text{ torr} = 101 \text{ kPa}$$

Consider a gas confined inside a container. The velocity and the number of collisions of the gas molecules affect the pressure of the gas inside the container. Any change that affects the velocity and/or number of collisions of those gas molecules (such as a change in volume or a change in temperature) will in turn result in a change in pressure. In order to establish the relationship between a change in volume (Boyle's Law) or a change in temperature (Gay-Lussac's Law) and the resulting change in pressure we need to review some mathematical relationships.

Two parameters can have a *direct relationship* (an increase in one parameter causes an increase in the second parameter) or an *inverse relationship* (an increase in one parameter causes a decrease in the second parameter). Furthermore, that relationship can be *linear* (a doubling of one parameter causes a doubling of the second parameter) or *non-linear* (a doubling of one parameter causes a change other than the doubling of the second parameter). One way to determine if a relationship is direct or inverse is to find a proportionality constant (k) from your (x,y) data pairs. If the relationship is direct and linear, then **k=y/x**. If it is inverse, so that the doubling of one parameter results in the halving of the other, then **k=x•y**.

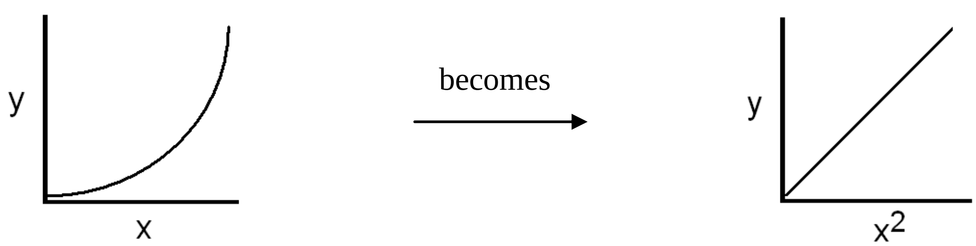
In this experiment you will determine whether a) the pressure and volume and b) the pressure and temperature of a confined gas are directly or inversely related, and whether that relationship is linear or non-linear.

Below are graphical examples of such relationships between sets of (x, y) data pairs:

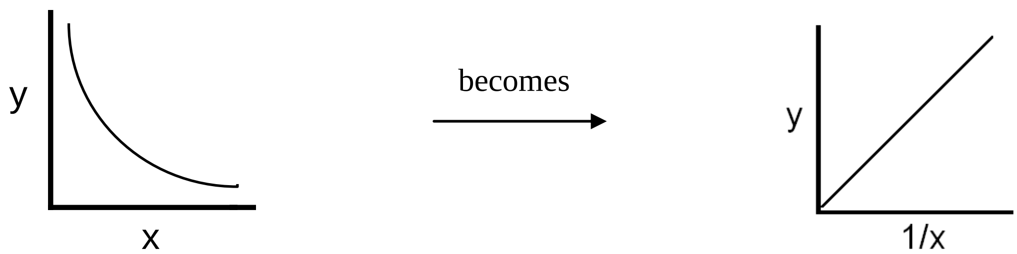


Linear relationships are easiest to work with. Some graphical manipulations allow many non-linear relationships to be converted into a linear relationship. Consider the following:

- a non-linear relationship is often one in which y varies *exponentially* with x. That is, y might vary with the *square* of x, the *cube* of x, etc. Such relationships become linear when you plot (respectively) y versus x^2, y versus x^3, etc. For example:



- a non-linear, inverse relationship where *doubling variable x reduces variable y in half* becomes a linear, direct relationship when you plot y vs. 1/x. You can also rationalize this backwards, that is, a graph of y vs. 1/x that yields a straight line confirms an inverse relationship between two variables, where doubling variable x reduces variable y in half.



II. LABORATORY BACKGROUND

A. The Effect of Volume on Pressure (Boyle's Law)

In order to determine the relationship between the pressure and volume of a confined gas, you will connect a syringe to a pressure sensor (Figure 1). The gas used will be air. It is assumed that *the amount (number of moles) of gas and the temperature of the gas inside the syringe will remain constant throughout the experiment*. When the volume of the syringe is changed by moving the piston, there is a resulting change in the pressure exerted by the confined gas. This pressure change will be monitored using a pressure sensor interfaced to a computer. Pressure and volume data pairs will be collected during this experiment and then analyzed. From the data and graph, you should be able to determine what kind of mathematical relationship exists between the pressure and volume of the confined gas.

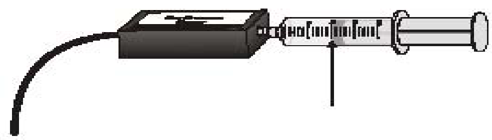


Figure 1

B. The Effect of Temperature on Pressure (Gay-Lussac's Law)

In this part of the experiment, you will study the relationship between the temperature of a gas sample and the pressure it exerts. The gas sample (air) will be placed inside a sealed Erlenmeyer flask, so that *the amount (number of moles) of gas and the volume of the gas will be kept constant throughout the experiment*. Using the apparatus shown in Figure 2, you will place the Erlenmeyer flask containing your air sample in water baths of varying temperature. Pressure will be monitored with a pressure sensor and temperature will be monitored using a temperature probe. Pressure and temperature data pairs will be collected during the experiment and then analyzed. From the data and graph, you will determine what kind of mathematical relationship exists between the pressure and absolute temperature of a confined gas.

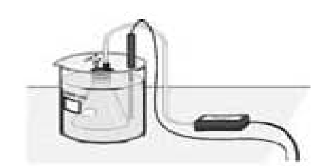


Figure 2

III. PRE-LAB QUESTIONS – Experiment: Gases

1. a) Complete the table below.

y	**x**	**1/x**	**y/x**	**x*y**
2	2			
1	4			
0.5	8			
0.25	16			

b) On graph paper plot y vs. x (appropriately labeling all axes as well as graphing the best fitting line/curve to the data points).

c) Is the relationship between the y and x data pairs linear or non-linear?

d) Is the relationship between the y and x data pairs direct or inverse?

e) Which expression of k (k=y/x or k=xy) corresponds to the relationship that you describe in parts c and d? (*i.e.* the expression where k is a constant)

2. a) Plot y vs. 1/x for the data in question 1.

b) Is the relationship linear or non-linear?

c) Is the relationship direct or inverse?

3. a) Complete the table below.

y	**x**	**y/x**	**x*y**
2	4		
4	8		
8	16		
16	32		

b) On graph paper plot y vs. x (appropriately labeling all axes as well as graphing the best fitting line/curve to the data points).

c) Is the relationship between the y and x data pairs linear or non-linear?

d) Is the relationship between the y and x data pairs direct or inverse?

e) Which expression of k (k=y/x or k=xy) corresponds to the relationship that you describe in parts c and d? (*i.e.* the expression where k is a constant)

IV. PROCEDURE

A. The Effect of Volume on Pressure (Boyle's Law)

1. With the syringe **disconnected** from the gas pressure sensor, pull the plunger back to the 10.0 mL mark (until the front edge of the inside black ring is on the 10.0 mL mark, as indicated by the arrow in Figure 3).

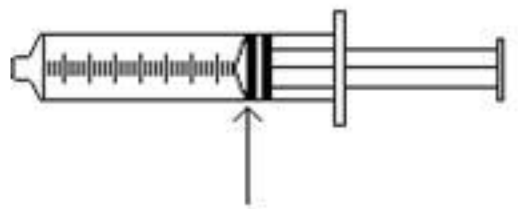


Figure 3

2. Attach the 20 mL syringe to the gas pressure sensor.

3. Click Collect to begin data collection.

4. Collect the pressure vs. volume data. It is best for one person to take care of the gas syringe and for another to operate the computer.

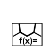
   • Move the piston to position the front edge of the inside black ring (see Fig. 3) at the 5.0-mL line on the syringe. Hold the piston firmly in this position until the pressure value stabilizes.

   • When the pressure reading has stabilized, click Keep. Type "5.0" for the volume.

5. Repeat the Step 4 procedure for volumes of 7.5, 10.0, 12.5, 15.0, 17.5, and 20.0 mL.

6. Click Stop when you have finished collecting data. In your data table, record the pressure and volume data pairs displayed in the Table window.

7. Examine the graph of pressure vs. volume (if needed to see all your data points, **Autoscale** from the **Analyze** menu). Based on this graph, decide what kind of mathematical relationship exists between these two variables (direct or inverse). To see if you made the right choice:

   • Click the Curve Fit button  .

   • Choose Variable Power (y = Ax^n) from the list at the lower left. Enter the power value, *n*, in the Power edit box that represents the relationship shown in the graph (e.g., type "1" if direct, "-1" if inverse). Click Try Fit.

- A best-fit curve will be displayed on the graph. If you made the correct choice, the curve should match up well with the points. If the curve does not match up well, try a different exponent and click [Try Fit] again. When the curve has a good fit with the data points, click [OK].

8. **Plot the pressure vs. volume graph manually** using the graph paper provided. You can also print your graph, if your instructor tells you to.

9. On your data sheet, calculate and record the reciprocal of volume (1/V), based on your original volume data.

10. **Plot pressure versus the reciprocal of volume (1/V)** using the graph paper provided. Draw the best-fit linear regression line for your data points. *Note: to generate and print this graph using your computer, follow the instructions listed in the* EXTENSION *section (see last page).*

11. Calculate the values of P/V and P•V, keeping in mind significant figures in rounding. Record in your data sheet.

12. Answer the questions on part A of your data sheet.

B. The Effect of Temperature on Pressure (Gay-Lussac's Law)

1. Prepare a boiling-water bath. Put about 800 mL of hot tap water into a l-L beaker and start heating the water to a boil using the Bunsen burner.

2. Prepare an ice-water bath. Put about 700 mL of cold tap water into a second 1-L beaker and add ice.

3. Put about 800 mL of room-temperature water into a third 1-L beaker.

4. Put about 800 mL of hot tap water into a fourth 1-L beaker.

5. An Erlenmeyer flask has been fitted with a rubber stopper that provides an airtight container that allows you to investigate the gas (air) trapped inside. *Make sure no air can go in or out of the flask by closing the blue handle on the 2-hole stopper*. Figure 4 shows the setup for your experiment:

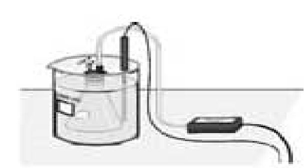


Figure 4

6. Click Collect to begin data collection.

7. Collect pressure vs. temperature data for your gas sample:

   - Place the flask into the ice-water bath. Make sure the entire flask is covered with water (see Figure 4).

   - Place the temperature probe into the ice-water bath. Stir the water gently with the temperature probe throughout the experiment.

   - When the pressure and temperature readings displayed in the Meter window (bottom left of screen) stabilize, click Keep. You have now saved the first pressure-temperature data pair.

8. Repeat step 7 using the room-temperature bath.

9. Repeat step 7 using the hot-water bath.

10. Repeat step 7 using the boiling water bath. Use a utility clamp to clamp the flask inside the boiling water bath. The temperature probe inside the water bath should not be touching the bottom of the flask. **CAUTION:** *Do not burn yourself or the probe wires with the Bunsen burner flame.*

11. Click Stop when you have finished collecting data. Turn off the Bunsen burner. Record the pressure and temperature values in your data table.

12. Examine the graph of pressure vs. temperature (^{o}C). If needed to see all your data points, **Autoscale** from the **Analyze** menu. In order to determine if the relationship between pressure and temperature is direct or inverse, your temperatures must be converted to the Kelvin scale. You can do this manually, or follow the instructions found in the EXTENSION section at the end of this lab to see your results on-screen. Below are instructions for the manual calculations and plotting.

13. Convert the Celsius temperatures into Kelvin temperatures by adding 273 to each Celsius temperature. Record in your data sheet.

14. **Plot pressure versus the temperature in Kelvin (K)** using the graph paper provided. Draw the best-fit linear regression line for your data points.

15. Calculate the values of P/T and P•T (using your Kelvin temperatures for T). Record in your data sheet, keeping in mind significant figures in rounding.

16. Answer the questions on part B of your data sheet.

DATA SHEET (pg. 1 of 2) **Name ________________________**

Experiment: Gases

A. Pressure vs. Volume (Boyle's Law)

Volume (mL)	Pressure (kPa)	1/V (1/mL)	P / V	P•V

PROCESSING THE DATA

1. According to your data, if the volume is *doubled* from 5.0 mL to 10.0 mL, what happens to the pressure? (Doubles? Triples? Halved/Reduced in half?)

2. According to your data, if the volume is *halved* from 20.0 mL to 10.0 mL, what happens to the pressure?

3. According to your data, if the volume is *tripled* from 5.0 mL to 15.0 mL, what happens to the pressure?

4. From your answers to the first three questions *and* the shape of the curve in the plot of pressure versus volume, do you think the relationship between the pressure and volume of a confined gas is direct or inverse?

5. Which expression of k (k=P/V or k=P•V) corresponds to the relationship between pressure and volume? (*Hint: the expression where the value of k is constant, or nearly so, from your data table).* This represents Boyle's law.

6. Calculate the average value of k from your data. Record the correctly rounded value below. Use that value of k and Boyle's law (the expression you arrived at in question 5) to calculate the new pressure if the volume of the syringe is increased to 40.0 mL.

B: Pressure vs. Temperature (Gay Lussac's Law)

Water Bath	**Pressure (kPa)**	**Temperature (°C)**	**Temperature (K)**	**P / T** ***(Use T in K!)***	**P•T** ***(Use T in K!)***
Ice					
Room temperature					
Hot					
Boiling					

PROCESSING THE DATA

1. In order to perform this experiment, what two experimental factors were kept constant?

2. Based on the data and graph that you obtained for this experiment, express in words the relationship between gas pressure and temperature (K). (direct or inverse, linear or not).

3. Which expression of k (k=P/T or k=P•T) corresponds to the relationship between pressure and temperature (K)? (*Hint: the expression where the value of k is constant, or nearly so, from your data table).* This represents Gay-Lussac's law.

4. According to this experiment, what should happen to the pressure of a gas if the Kelvin temperature is doubled?

5. Calculate P/T for all the data pairs in your table, using T in Celsius. Does Gay-Lussac's law still hold true (is k still constant) if we use temperatures in Celsius?

EXTENSION

Instructions to plot pressure versus the reciprocal of volume (1/V) using Logger*Pro.*

1. Create a new column of data, reciprocal of volume, based on your original volume data.

   - Remove the Curve Fit box from the graph by clicking on its upper-left corner.
   - Choose New Calculated Column from the **Data** menu.
   - Enter “1/Volume” as the Name, “1/V” as the Short Name, and “1/mL” as the Unit. Enter the correct formula for the column (1/volume) into the Equation box. To do this, type in “1” and “/”. Then select “Volume” from the Variables list. In the Equation box, you should now see displayed: 1/“Volume”. Click Done.
   - Click on the horizontal-axis label, select “1/Volume” to be displayed on the horizontal axis.

2. Click on the Linear Regression button, . A best-fit linear regression line will be shown for your data points. If the relationship between these data points (P and 1/V) is direct and linear, the linear regression line should pass through (or near) your data points.

Instructions to plot pressure versus temperature (K) using Logger*Pro.*

1. You can create a new data column for Kelvin temperature as follows:

   - Choose New Calculated Column from the **Data** menu.
   - Enter “Temp (K)” as the Name, “T (K)” as the Short Name, and “K” as the Unit.
   - Enter the correct formula for the column into the Equation box. Type in “273+”. Then select “Temp Celsius” from the Variables list. In the Equation box, you should now see displayed: 273+“Temp Celsius”. Click Done.
   - Click on the horizontal-axis label, select “Temp (K)” to be displayed on the horizontal axis.
   - If necessary, choose **Autoscale** from the **Analyze** drop-down menu.

2. Click on the Linear Regression button, . A best-fit linear regression line will be shown for your data points. If the relationship between these data points (P and T(K)) is direct and linear, the linear regression line should pass through (or near) your data points.