Lab 6: Gas Laws

Objective: To investigate gas laws; Boyle's law and Gay-Lussac's law. Boyle's law studies the relationship between the pressure and the volume occupied by a gas when temperature and moles of gas are held constant. Gay-Lussac's law studies the relationship between the pressure and absolute temperature of a gas when volume and moles of gas are held constant.

Materials: Ice, water.

Equipment: Gas pressure sensor, temperature probe, hot plate, 250 mL Erlenmeyer flask, four 1L beakers, stir bar, ring stand and clamp.

Safety: Wear safety goggles and gloves at all times in the lab.

INTRODUCTION

As one of the three states of matter, gases have unique properties. They are readily compressible, and the volume occupied by a gas is affected dramatically by changes in temperature and pressure. Furthermore, the behavior of gases is governed by a well-defined set of laws that are applicable to all gases, regardless of chemical identity.

Our understanding of the behavior of gases began with the work of Robert Boyle, who published his results in 1622. **Boyle's Law** states that the **volume occupied by a gas (at constant temperature and moles of gas) is inversely related to the pressure of the gas**. This relationship can be represented mathematically as:

Equation 6.1. $$V \propto \frac{1}{P}$$

where V is the volume occupied by the gas at some pressure, P. Equation 6.1 can also be written as:

Equation 6.2. $$V = \frac{k_1}{P}$$

where k_1 is a proportionality constant.

More than a century later, the work of Jacques Charles and Joseph Gay-Lussac provided insight into the relationship between the temperature and volume of a gas. Gay-Lussac noted that the volume occupied by a gas decreases as temperature decreases, which led to the definition of **absolute zero** and the **Kelvin scale**. Temperatures on the Celsius scale can be converted to absolute (Kelvin) temperatures by Equation 6.3.

Equation 6.3. $T = 273.15 + t$

where T is the absolute temperature (in kelvins) and t is the temperature in Celsius. **Charles' Law** quantifies the relationship between temperature and volume and states that **the volume occupied by a gas (at constant pressure and moles of gas) is directly proportional to its absolute temperature**. Charles' Law is represented mathematically as:

Equation 6.4. $V \propto T$

or

Equation 6.5. $V = k_2 T$

where T is absolute temperature (in kelvins) and k_2 is a proportionality constant.

Gay-Lussac is also credited for the discovery of relationship between the pressure and absolute temperature of a gas. Gay-Lussac's Law states that **pressure of a gas is directly proportional to its absolute temperature (at constant volume and moles of gas).** Gay-Lussac's Law is represented mathematically as:

Equation 6.6. $P \propto T$

or

Equation 6.7. $P = k_3 T$

Boyle's Law and Charles' Law can be rearranged as:

Boyle's Law: Equation 6.8. $PV = k_1$
Equation 6.9. $P_1V_1 = P_2V_2$

Charles' Law: Equation 6.10. $V/T = k_2$
Equation 6.11. $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

We can combine Equations 6.8 and 6.10 into the **combined gas law**, which is given in Equation 6.12:

Equation 6.12. $\frac{P \cdot V}{T} = k_4$

One advantage of the combined gas law is that it allows us to compare the temperature, pressure, and volume of a gas sample under two different sets of conditions, where:

Equation 6.13. $\left(\frac{P_1V_1}{T_1}\right) = \left(\frac{P_2V_2}{T_2}\right)$

If the volume of a gas sample is known at one set of conditions (T_1, P_1), the volume can be calculated under another set of conditions (T_2, P_2).

Intuitively, the volume occupied by a gas would be expected to increase in proportion to the number of moles of gas in the sample. This relationship, known as **Avogadro's Law**, can be represented as:

Equation 6.14. $V = k_5n$

Equations 6.8, 6.10, and 6.14 can now be combined to yield the **ideal gas law**, Equation 6.15:

Equation 6.15. $PV = nRT$

where R is the proportionality constant known as the universal gas constant. The value of R is the same for all ideal gases. An "ideal gas" is defined as one whose behavior can be described exactly by the gas laws presented here. Nearly all gases exhibit ideal behavior under standard conditions. Deviations from ideal behavior are observed, however, for polar gases at low temperatures and high pressures.

In the first part of this experiment, you will investigate the Boyle's Law using a sample of air. Boyles law studies the relationship between pressure and volume of a gas. When the pressure is plotted against volume it will yield a curving graph, Figure 6.1, but when pressure is plotted against $\frac{1}{volume}$ it will yield a straight line.

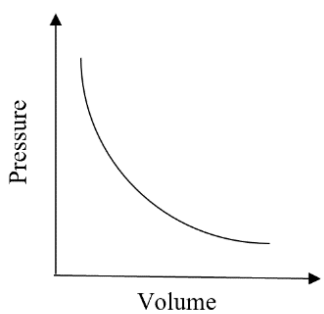

Figure 6.1. Pressure- volume graph

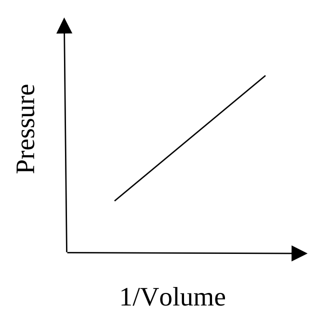

Figure 6.2. Pressure and volume are inversely proportional

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In the second part, you will investigate Gay-Lussac's Law ($P \propto T$), again using a sample of air. The pressure is directly proportional to the absolute temperature and when pressure is plotted vs. temperature is will yield a straight-line graph as shown in Figure 6.3.

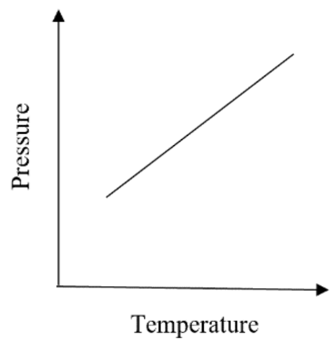


Figure 6.3. Pressure and absolute temperature of a gas are directly proportional

Pre-Lab Questions

1. Define the ideal gas laws:

    a. Boyle's law:

    b. Charles's law:

    c. Gay-Lussac's law:

    d. Avogadro's law:

2. (a) Calculate the volume of one mole of hydrogen gas at 273 K and 760 torr. (Use a value of R = 0.0821 L·atm/mol·K.)

    (b) Would you expect the volume of one mole of oxygen gas under the same conditions to be the same or different? Explain.

3. Two moles of an ideal gas originally at 380 torr and 298 K are compressed at constant temperature to a final pressure of 680 torr. Use the ideal gas law to calculate the volumes of gas at the initial and final pressures.

    Initial volume (at 380 torr): _______________

    Final volume (at 680 torr): _______________

4. What is the gas that will be used in this experiment?

PROCEDURE

Part A. Boyle's Law

In this part, you will study the relationship between the pressure of a gas and its volume when temperature and moles of gas are held constant. The gas used in this experiment is air.

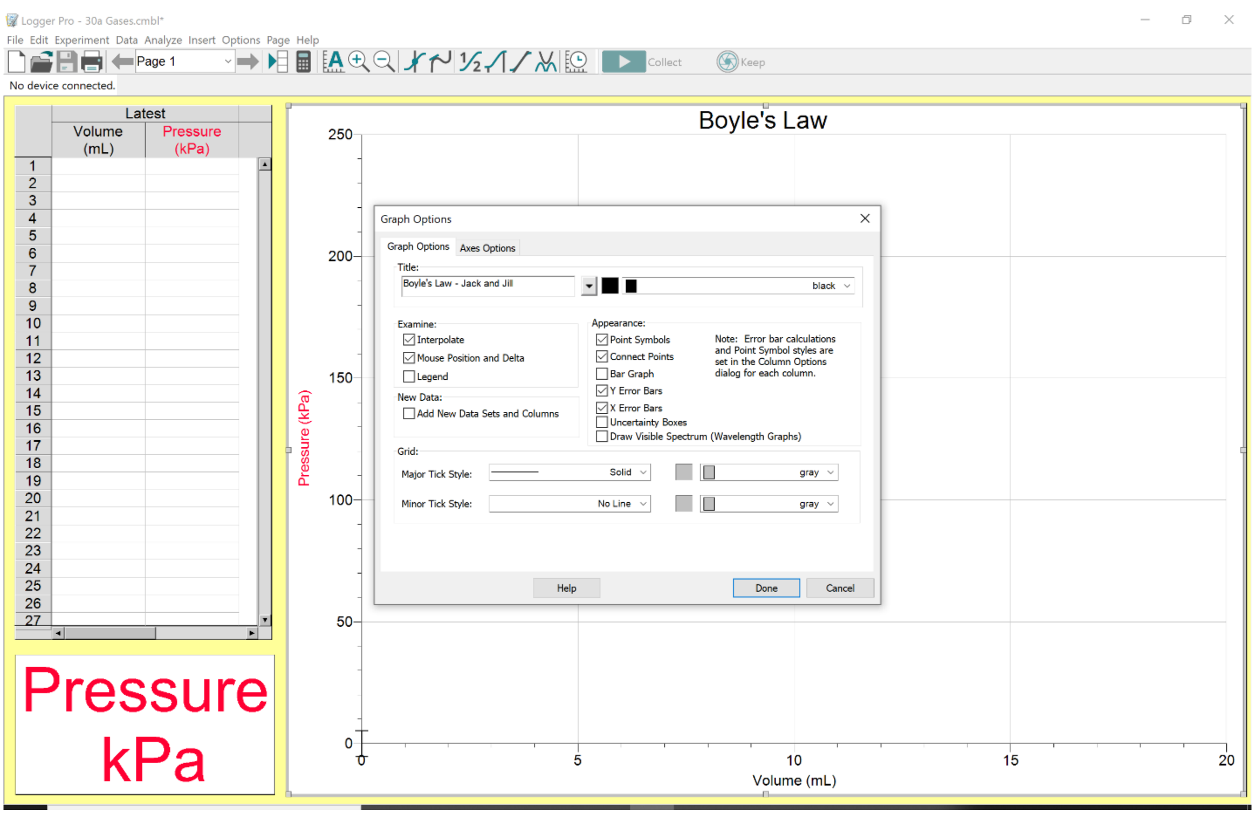
1. Plug in the gas pressure sensor to Channel 1 of Lab Quest interface.

2. Log into the desktop using your NIU credentials and open Logger Pro.

3. From File menu open **Advanced Chemistry with Vernier**, and **30a Gases.** This will allow you to collect pressure data using *Events with Entry* mode. In this mode, for each pressure reading, the software asks you to enter a volume value.

4. To have a proper view of the graph, right click anywhere on the graph, from **Graph Options**, change the title to "Boyle's Law", add the names of lab partners, click **Connect Points.**

5. From **Axes Options** tab, choose **Autoscale** for Y and X axes, so that you can see all the data points on the screen. Click **Done**.



6. Obtain all the parts necessary to construct the apparatus shown in Figure 6.1. Be sure that the syringe piston slides easily when pressure applied.

7. Move the piston of the syringe back until the front edge of the inside black ring is at 10 mL.

8. With a gentle half turn attach the syringe to the valve of the gas pressure sensor. Do not overtighten. The sensor is very sensitive to pressure.

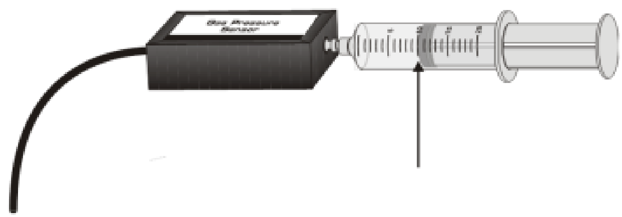


Figure 6.1. Gas pressure sensor
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Do not detach the syringe until you have collected all the data. Unplugging the syringe will cause air to get in and number of moles of gas to change.

Keep in mind that you'll need to add 0.7 mL to the volumes measured in the syringe to account for the volume between the end of the syringe and the inside of the gas pressure sensor box.

It is best if two people to work together to collect the data. One person should hold the piston and the other one monitors the pressure and click **Keep**.

9. Click **Collect** to start the data collection. Do not push **Stop** until you have collected all the data.

10. Move the piston until the front edge of the inside black ring is at 4 mL. Hold the piston at this position and wait for the pressure reading to stabilize. Press **Keep**.

11. Enter the gas volume, 4.0 + 0.7= 4.7 mL. Click **OK**.

12. Repeat the steps to collect pressure data for volumes 6.0, 8.0, 10.0, 12.0, 14.0, 16.0, 18.0 mL and 20.0 mL. Remember to add 0.7 to each volume.

13. Click **Stop** when you have collected pressure data for all volumes.

14. Record the volume – pressure data in data sheet.

Data Analysis

15. From **Analyze** menu, choose **Curve Fit**.
    a. Try different fits to find the best fit for your curve. Check each fit and **Try Fit**.
    b. The best fit should have a correlation close to 1 and the minimum RMSE (Root Mean Square Error).
    RMSE is one of the most used measures for evaluating the quality of predictions. It shows how far predictions fall from measured true values.
    c. Once you have determined the best fit take a screenshot of the graph and save a digital copy of the graph. You need to submit a copy of this graph along with your report.

Note: Click **Cancel** if a **Print Setup** menu appears. Choosing a printer from this menu may cause the software to become nonresponsive.

d. From **Analyze** choose **Interpolate**. A vertical curser will appear on the graph and the volume- pressure data is displayed in a box.
e. Answer questions 1 and 2 on datasheet before moving to the next step.

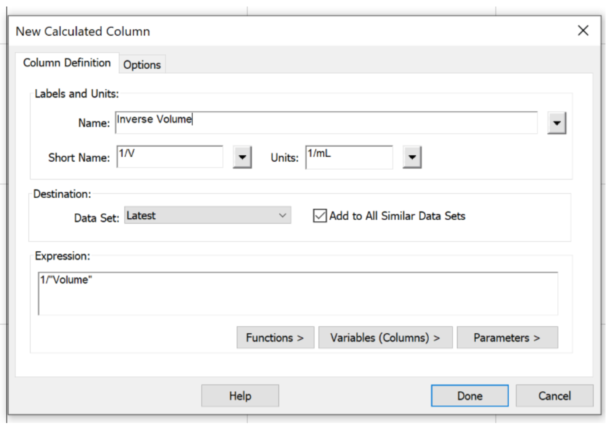
16. You have collected *P* vs. *V* data but to investigate the Boyle's law you need to create a new calculated column which contains the reciprocal values of volume (1/*V*) and plot *P* vs. 1/*V*.

To create a 1/V column:

a. From **Data**, choose **New Calculated Column**, name the column *1/ Volume*, give it a short name (1/*V*) and units (1/*mL*).
b. In the **Expression** box, type **1/"Volume"**, click **Done**. This will take a reciprocal of values in Volume column and record in in 1/Volume column.

To plot P vs. 1/V:

c. Click **Options** > **Graph Options** > Change the **Title** to "P vs. 1/V", add the names of lab partners.
d. Open **Axes Options**, for **Y-axis Columns** choose **Pressure (kPa)**, and for **X-Axis, Column**, choose **1/ Volume (1/mL)**. Click **Done**.
e. You should now see a plot of *P* vs. 1/*V*. Is this graph different from the first one? How?
f. Save a digital copy of this graph and submit along with your report.



17. Close the program. Do not save.
18. Gently disconnect the syringe and place in proper storage.

Part B. Gay-Lussac's Law

In this part, you will study the relationship between the pressure of a gas (a sample of air) and its absolute temperature when its volume and moles of gas are held constant, and the data collection will be "Event Based" on Logger Pro. Obtain an Erlenmeyer flask, four 1 L beaker, and a temperature probe. The Erlenmeyer flask containing the gas sample (air) will be placed in a water bath at four different temperatures: hot, warm, room temperature and ice and each temperature will be labeled as an "Event" on Logger Pro.

If the pressure reading does not change at each different temperature change, there is an issue with your assembly, most likely there is a leak in the system. Save your water baths to the end until you have evaluated your data.

19. Gently attach the valve assembly to the gas pressure sensor. With gas pressure sensor still connected to **Channel 1**, connect the temperature probe to **Channel 2** of the LabQuest interface.

20. Start by collecting pressure data for hot water bath. Place a large magnetic stir bar in a 1 L beaker, add about 700 mL deionized water and place the beaker on a hot plate. Do not turn on the heater yet!

21. Assemble the apparatus as shown in Figure 6.2. Be sure all fittings are airtight, and the rubber stopper and flask neck are dry. Twist and push down the rubber stopper to ensure a tight fit.

If the stopper is not tight enough it will pop out and you have to start over.

22. Close the valve on the assembly.

23. Turn on the heat to a high setting and the stirrer to a medium setting. The best result for hot water bath is obtained when water is boiling. Use hot gloves and beaker tongs when handling the boiling water.

24. From file menu, open the file **"30b Gases"** from the ***Advanced Chemistry with Vernier*** folder. This file is set up to collect pressure and temperature data (in Kelvin) from the attached sensors, using Selected Events mode. This mode allows you to collect a pressure-temperature data pair simultaneously for each event. In this experiment, each water bath is defined as an Event.

25. To begin data collection for hot water bath, click **Collect**.

26. While waiting for water to boil start preparing room temperature and ice water baths.

    a. Room temperature water bath: Add 700 mL deionized water in a clean 1 L beaker.

    b. Ice water bath: Add about 600 mL ice in a clean dry 1 L beaker and add deionized water to 700 mL.

27. When water starts boiling, and both the pressure and temperature readings are stabilized, click **Keep.** The number of events will be automatically generated in the data table.

28. Turn off the hot plate/stirrer.

29. Using hot gloves, carefully loosen the clamp and slowly move up the flask + temperature probe assembly so that the hot water beaker and the hot plate can be removed. Do not move the fittings, only the clamp.

30. Prepare a warm water bath by adding about 350 mL of hot water and 350 mL deionized water into a fourth 1 L beaker.

31. Place the warm temperature bath under the flask + temperature probe assembly and slowly lower the clamp until the flask is submerged in warm water bath. When temperature and pressure readings are stable, click **Keep.** It may take several minutes for readings to stabilize. Be patient.

32. Repeat to collect the pressure data for room temperature and ice water baths.

33. Click **Stop** after you have collected the pressure data forall four water baths. Record the pressure – temperature data in datasheet.

Data Analysis

34. From **Analyze** choose **Linear Fit** to have the best fit for your graph.

35. Click **Options** > **Graph Options** > Change the **Title** to “Gay-Lussac’ Law”, add the names of lab partners.

36. Repeat the instructions given before to save a digital copy of this graph and upload it with your report.

37. From **Analyze** choose **Interpolate**. A vertical curser will appear on the graph and the temperature- pressure data is displayed in a box.

38. Move the cursor along temperature axis and answer questions 3 and 4 on datasheet.

39. Close the program. Do not save.

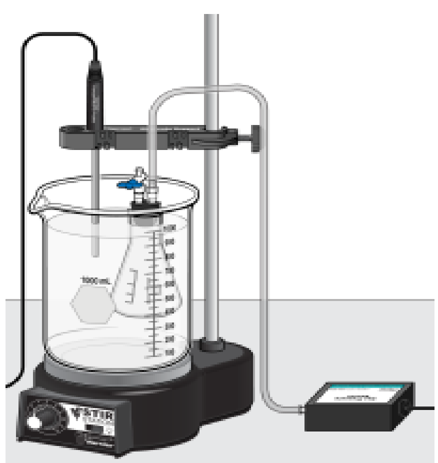


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Figure 6.2. Pressure – temperature apparatus

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Data Sheet

Part A. Pressure-Volume

Volume (mL)	**Pressure (kPa)**

1. Move the cursor until volume is at 6.0 mL Record the pressure value. Next, move the cursor to 12.0 and 18.0 mL volume and record the corresponding pressures.

Volume (mL)	**Pressure (kPa)**
6.0	**178.8**
12.0	
18.0	

2. Move the cursor until volume is at 20.0 mL Record the pressure value. Next, move the cursor to 10.0 and 5.0 mL volume and record the corresponding pressures.

Volume (mL)	**Pressure (kPa)**
20.0	
10.0	
5.0	

Attach a copy of *P* vs. *V* and *P* vs. *1/V* graphs to your report.

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Data Sheet

Part B. Pressure-Temperature Data

Temperature (K)	Pressure (kPa)

3. Move the cursor to 300, 150 and 100 K. Record the corresponding pressure for each temperature. You may need to change the minimum/maximum values of the axes by clicking **Options** > **Graph Options** > **Axes Options.**

Temperature (K)	Pressure (kPa)
300	
150	
100	

4. Move the cursor to 200 and 400 K. Record the corresponding pressure for each temperature.

Temperature (K)	Pressure (kPa)
200	
400	

Attach a copy of *P* vs. *T* graph to your report.

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Post-Lab Questions

1. Examine your Boyle's Law data and answer the following questions:
   a. What happens to pressure when volume is doubled?
   b. What happens to pressure when volume is tripled?
   c. What happens to pressure when volume is halved?
   d. What happens to pressure when volume is reduced by ¼?
   e. Are your results in good agreement with Boyle's law?

2. Comment on why the shape of P-V and P – 1/V graphs are different.

3. Boyle's law states that pressure and volume of an ideal gas are inversely proportional when the temperature and moles (*n*) of gas are constant. Explain how the temperature and moles of gas were held constant during the first part of this experiment.

4. Examine your Gay-Lussac's Law data and answer the following questions:
   a. What happen to pressure when temperature is decreased by 1/3?
   b. What happens to pressure when temperature is doubled?
   c. Are your results in good agreement with Gay-Lussac's law?

5. Gay-Lussac's Law states that the pressure and absolute temperature of an ideal gas are directly proportional when the volume and moles (*n*) of gas are constant. Explain how the volume and moles of gas were held constant during the second part of this experiment.