Boyle's Law: Pressure-Volume Relationship in Gases

The primary objective of this experiment is to determine the relationship between the pressure and volume of a confined gas. The gas we use will be air, and it will be confined in a syringe connected to a Gas Pressure Sensor (see Figure 1). When the volume of the syringe is changed by moving the piston, a change occurs in the pressure exerted by the confined gas. This pressure change will be monitored using a Gas Pressure Sensor. It is assumed that temperature will be constant throughout the experiment. 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. Historically, this relationship was first established by Robert Boyle in 1662 and has since been known as Boyle's law.

OBJECTIVES

In this experiment, you will

- Use a Gas Pressure Sensor and a gas syringe to measure the pressure of an air sample at several different volumes.
- Determine the relationship between pressure and volume of the gas.
- Describe the relationship between gas pressure and volume in a mathematical equation.
- Use the results to predict the pressure at other volumes.

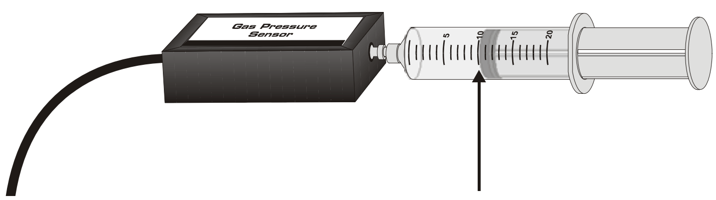

Figure 1

MATERIALS

TI-Nspire handheld **or**
computer and TI-Nspire software
data-collection interface
Vernier Gas Pressure Sensor
20 mL gas syringe

PROCEDURE

1. Prepare the Gas Pressure Sensor and an air sample for data collection.
   a. With the 20 mL syringe disconnected from the Gas Pressure Sensor, move the piston of the syringe until the front edge of the inside black ring (indicated by the arrow in Figure 1) is positioned at the 10.0 mL mark.
   b. Attach the 20 mL syringe to the valve of the Gas Pressure Sensor.

2. Connect the Gas Pressure Sensor to the data-collection interface. Connect the interface to the TI-Nspire handheld or computer.

3. Choose New Experiment from the Experiment menu. Choose Collection Mode ► Events with Entry from the Experiment menu. Enter **Volume** as the Name and **mL** as the Units. Select OK.

4. To obtain the best data possible, you will need to correct the volume readings from the syringe. Look at the syringe; its scale reports its own internal volume. However, that volume is not the total volume of trapped air in your system since there is a little bit of space inside the pressure sensor.

   To account for the extra volume in the system, you will need to add 0.8 mL to your syringe readings. For example, with a 5.0 mL syringe volume, the total volume would be 5.8 mL. It is this total volume that you will need for the analysis.

5. You are now ready to collect pressure and volume data. It is easiest if one person works with the gas syringe and another person enters volumes.
   a. Start data collection ( ).
   b. Move the piston so the front edge of the inside black ring (see Figure 2) is positioned at the 5.0 mL line on the syringe. Hold the piston firmly in this position until the pressure value displayed on the screen stabilizes.
   c. Click the Keep button ( ) and enter **5.8**, the gas volume (in mL). Remember, you are adding 0.8 mL to the volume of the syringe for the total volume. Select OK to store this pressure-volume data pair.

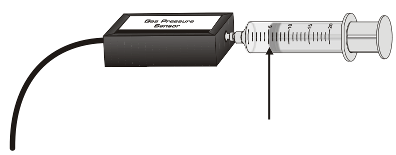

Figure 2

   d. Continue this procedure using syringe volumes of 7.0, 9.0, 11.0, 13.0, 15.0, 17.0, and 19.0 mL. After collecting the second data point, autoscale the graph by choosing Autoscale Now from the Graph menu.
   e. Stop data collection ( ).

6. When data collection is complete, a graph of pressure *vs.* volume will be displayed. Click Table View ( ). Record the pressure and volume data values in Table 1.

7. Based on the graph of pressure *vs.* volume, decide what kind of mathematical relationship exists between these two variables, direct or inverse. To see if you made the right choice:
   a. Click the Graph View tab ( ).
   b. Choose Curve Fit ►Power from the Analyze menu. The curve fit statistics for these two data columns are displayed for the equation in the form

   $$y = ax\text{^}b$$

   where x is volume, y is pressure, a is a proportionality constant, and b is the exponent of x (volume) in this equation. **Note:** The relationship between pressure and volume can be determined from the value and sign of the exponent, b.
   c. If you have correctly determined the mathematical relationship, the regression line should very nearly *fit* the points on the graph (that is, pass through or near the plotted points).

8. (optional) If directed by your instructor, proceed directly to the Extension.

DATA

Table 1		
Volume (mL)	Pressure (kPa)	Constant, k (P/V or P•V)

Table 2: Values based on Power Fit	
Volume (mL)	Pressure (kPa)
5.0	
10.0	
15.0	
20.0	

PROCESSING THE DATA

1. With the Power Fit curve still displayed, choose Interpolate from the Analyze menu. Move the cursor along the regression line until the volume value is 5.0 mL. Record the values in table 2.

2. Continue moving the cursor along the line to find the predicted pressure values for volumes of 10.0, 15.0 and 20.0 mL. Record these values in Table 2.

3. Determine if the relationship between pressure and volume is inverse or direct by finding the proportionality constant, k, from the data. The value for k will be constant for all values of P and V. If this relationship is direct, $k = P/V$. If it is inverse, $k = P•V$.
   a. Choose New Calculated Column from the Data menu.
   b. Enter **P over V** as the Name, **P/V** as the Short Name, and **kPa/mL** as the Units.
   c. Enter **Pressure/Volume** as the Expression. **Note:** The terms “Pressure” and “Volume” must exactly match the names of these columns. If you are unsure how it was entered, the available column names can be found below the Expression entry box.
   d. Select OK.
   e. Repeat steps a-d for pressure times volume. Enter **P times V** as the Name, **P*V** as the Short Name and **kPa*mL** as the units. Enter **Pressure*Volume** as the Expression.
   f. In the column provided in Table 1, enter the values for k from either P/V or $P•V$. Choose the calculation for k that shows k to be relatively constant.

QUESTIONS

1. What does your data show happens to the pressure when the volume is *doubled* from 5 mL to 10 mL?

2. What does your data show happens to the pressure if the volume is *halved* from 20 mL to 10 mL?

3. What does your data show happens to the pressure if the volume is *tripled* from 5.0 mL to 15.0 mL?

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

5. Based on your data, what would you expect the pressure to be if the volume of the syringe was increased to 40.0 mL? Explain or show work to support your answer.

6. Based on your data, what would you expect the pressure to be if the volume of the syringe was decreased to 2.5 mL? Explain or show work to support your answer.

7. What experimental factors are assumed to be constant in this experiment?

8. Based on your work for Step 3 in Processing the Data, is the relationship between pressure and volume direct or inverse? Explain your answer.

9. How *constant* were the values for k you recorded in Table 1?

10. Using P, V, and k, write an equation representing Boyle’s law. Write a verbal statement that correctly expresses Boyle’s law.

EXTENSION

1. To confirm that an inverse relationship exists between pressure and volume, a graph of pressure *vs. reciprocal of volume* (1/volume) may also be plotted.
   a. Choose New Calculated Column from the Data menu.
   b. Enter **ReciprocalVol** as the Name, **1/V** as the Short Name, and **1/mL** as the Units.
   c. Enter **1/Volume** as the Expression. **Note:** The term "Volume" must be entered exactly as it was entered when you set up data collection. If you are unsure how it was entered, the available column names can be found below the Expression entry box.
   d. Select OK.
2. Set up the graph of pressure *vs*. reciprocal of volume
   a. Choose Select X-axis Column ► ReciprocalVol from the Graph menu. Ensure that pressure is plotted on the y-axis and that reciprocal of volume is on the x-axis.
   b. Choose Window Settings from the Graph menu.
   c. Enter **0** as the values for X Min and Y Min.
   d. Select OK.
3. Follow this procedure to calculate regression statistics and to plot a best-fit regression line on your graph of pressure *vs*. reciprocal of volume:
   a. Choose Curve Fit ► Linear from the Analyze menu. The linear-regression statistics for these two data columns are displayed in the form:

   $$y = mx + b$$

   where x is 1/volume, y is pressure, m is a proportionality constant, and b is the y-intercept.
   b. If the relationship between P and V is an inverse relationship, the graph of pressure *vs.* reciprocal of volume should be direct; that is, the curve should be linear and pass through (or near) the origin. Examine your graph to see if this is true for your data.