Names_____

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

- 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.

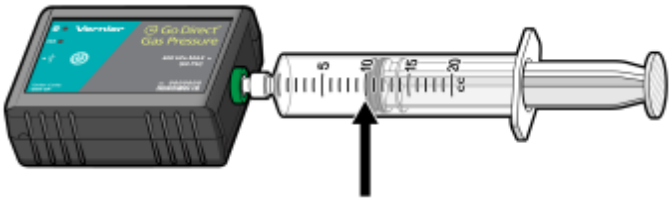

Figure 1

Make sure to read the volume from the black line of the plunger closest to the sensor as indicated above by the arrow.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct Gas Pressure
20 mL gas syringe

PROCEDURE

1. Prepare the data-collection equipment and an air sample for data collection.

   a. Launch Graphical Analysis. Connect the Gas Pressure Sensor to your Chromebook, computer, or mobile device. You may connect it by USB or by Bluetooth.

   b. 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.

   c. Attach the 20 mL syringe to the valve of the Gas Pressure Sensor.

2. Set up the data-collection mode.

   a. Click or tap Mode to open Data Collection Settings. Change Mode to Event Based.

   b. Enter **Volume** as the Event Name and **mL** as the Units. Click or tap Done.

3. You are now ready to collect pressure and volume data. It is easiest if one person takes care of the gas syringe and another enters volumes.

   a. Click or tap Collect to 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 or tap Keep and enter **5.0**, the gas volume (in mL). Click or tap Keep Point to store this pressure-volume data pair.

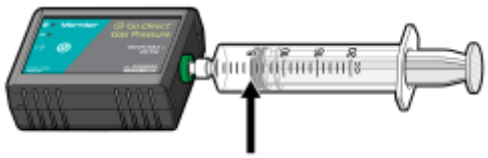

Figure 2

   d. Continue this procedure using syringe volumes of **7.5**, **10.0, 12.5, 15.0, 17.5, and 20.0 mL.**

   e. After you have collected all points above click or tap Stop to stop data collection.

5. Click graph tools, , and Add Annotation. Add your names to the graph.

6. When data collection is complete, a graph of pressure *vs*. volume will be displayed. To examine the data pairs on the displayed graph, tap any data point. As you tap each data point, the pressure and volume values are displayed to the right of the graph. Record the pressure and volume data values in your data table.

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 or tap Graph Tools, , and choose Apply Curve Fit.

   b. Select Power as the curve fit and Dismiss the Curve Fit box. The curve fit statistics are displayed for the equation in the form

   $$y = ax^b$$

   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).

   d. Rescale the axes on your graph by clicking or tapping Graph Tools, . Choose Edit Graph Options and set the x-axis to display 0 to 25 mL and the y-axis to display 0 to 300 kPa. Dismiss the Graph Options box.

   e. Print the graph with the curve fit displayed. To print, take a screen shot and email me with the screenshot in the body of the email with the subject **lab printout**

   f. Attach the graph to your lab

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. To do this, it is necessary to create a new column of data, reciprocal of volume, based on your original volume data:

   a. Click or tap More Options, ⋯, in the **Volume** column header in the table. Choose Add Calculated Column. Note, do not click the box above volume, but right next to the words volume (mL)…

   b. Enter **1/volume** as the Name and **1/mL** as the Units.

   c. Click or tap Insert Expression and choose A/X as the expression.

   d. Enter **1** as Parameter A and select Volume as the Column.

   e. Click or tap Apply.

2. Plot a best-fit regression line on your graph of pressure *vs*. 1/volume:

   a. Click on the volume label on the x axis and change it to 1/volume

   b. Click or tap Graph Tools, , and choose Edit Graph Options.

   c. Enter **0** as the value for both the Left value for the x-axis and the Bottom value for the y-axis.

   d. Dismiss the Graph Options box. Your graph should now include the origin (0,0).

   e. Click or tap Graph Tools, , and choose Apply Curve Fit.

   f. Select Linear as the curve fit and Dismiss the Curve Fit box. The linear-regression statistics 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.

   f. If the relationship between P and V is an inverse relationship, the graph of pressure *vs*. 1/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.

   g. Print a copy of this graph by emailing a screenshot to me with the subject **lab printout**

   h. Attach the graph to the lab.

PROCESSING THE DATA

1. Click on 1/volume on the x axis and switch it back to volume. With the best-fit curve still displayed, click or tap Graph Tools, , and turn on Interpolate. Dismiss the Graph Tools box and click the graph to interpolate. Move along the regression line until the volume value is 5.0 mL. Note the corresponding pressure value. Now move to the point where the volume value is doubled (10.0 mL). What does your data show happens to the pressure when the volume is *doubled*? Show the pressure values in your answer.

2. Using the same technique as in Question 1, what does your data show happens to the pressure if the volume is *halved* from 20.0 mL to 10.0 mL? Show the pressure values in your answer.

3. Using the same technique as in Question 1, what does your data show happens to the pressure if the volume is *tripled* from 5.0 mL to 15.0 mL? Show the pressure values in your answer.

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

9. One way to determine if a relationship is inverse or direct is to find a proportionality constant, *k*, from the data. If this relationship is direct, $k = P/V$. If it is inverse, $k = P \cdot V$. Based on your answer to Question 4, choose one of these formulas and calculate *k* for the seven ordered pairs in your data table (divide or multiply the *P* and *V* values). Show the answers in the third column of the Data and Calculations table.

DATA AND CALCULATIONS

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