  Graphical Analysis 6

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.

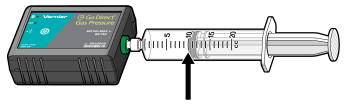


Figure 1

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.
   1. Launch Graphical Analysis. Connect the Gas Pressure Sensor to your Chromebook, computer, or mobile device.
   2. 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.
   3. Attach the 20 mL syringe to the valve of the Gas Pressure Sensor.
2. Set up the data-collection mode.
   1. Click or tap Mode to open Data Collection Settings. Change Mode to Event Based.
   2. Enter Volume as the Event Name and mL as the Units. Click or tap Done.
3. 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.

1. 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.
   1. Click or tap Collect to start data collection.
   2. 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.
   3. Click or tap Keep 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. Click or tap Keep Point to store this pressure-volume data pair.

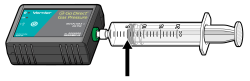


Figure 2

* 1. Continue this procedure using syringe volumes of 10.0, 12.5, 15.0, 17.5, and 20.0 mL.
  2. Click or tap Stop to stop data collection.

1. 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.
2. 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:
   1. Click or tap Graph Tools, , and choose Apply Curve Fit.



* 1. 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 = axb

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.

* 1. 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).
  2. 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.



* 1. (optional) Export, download, or print the graph with the curve fit displayed.

1. With the best-fit curve still displayed, proceed directly to the Processing the Data section.

DATA and calculations

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

PROCESSING THE DATA

1. 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.



1. 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.
2. 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.
3. 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.
4. 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.
5. 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.
6. What experimental factors are assumed to be constant in this experiment?
7. 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•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.
8. How constant were the values for k you obtained in Question 8? Good data may show some minor variation, but the values for k should be relatively constant.
9. 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. To do this, it is necessary to create a new column of data, reciprocal of volume, based on your original volume data:
   1. Click or tap More Options, , in the Volume column header in the table. Choose Add Calculated Column.



* 1. Enter 1/volume as the Name and 1/mL as the Units.
  2. Click or tap Insert Expression and choose A/X as the expression.
  3. Enter 1 as Parameter A and select Volume as the Column.
  4. Click or tap Apply.

1. Plot a best-fit regression line on your graph of pressure vs. 1/volume:
   1. Click or tap Graph Tools, , and choose Edit Graph Options.



* 1. Enter 0 as the value for both the Left value for the x-axis and the Bottom value for the y-axis.
  2. Dismiss the Graph Options box. Your graph should now include the origin (0,0).
  3. Click or tap Graph Tools, , and choose Apply Curve Fit.



* 1. 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.

* 1. 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.