

Boyles Law

module 7

Pressure & Volume Relationship

Name: \_\_\_\_\_ Section Number: \_\_\_\_\_ Score: \_\_\_\_\_

## Gas Law's: 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.

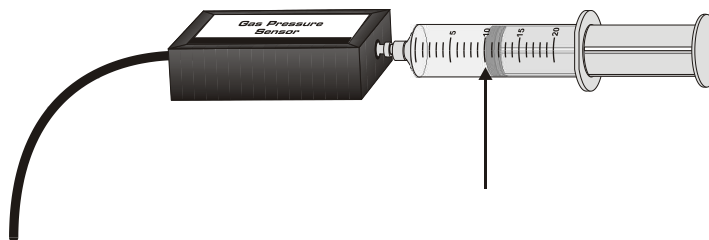


Figure 1

### MATERIALS

LabQuest  
LabQuest App

Vernier Gas Pressure Sensor  
20 mL gas syringe

### PROCEDURE

1. Prepare the Gas Pressure Sensor and an air sample for data collection.
  - a. Connect the Gas Pressure Sensor to LabQuest and choose New from the File menu. If you have an older sensor that does not auto-ID, manually set up the sensor.
  - 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.

### LabQuest 2A

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- c. Attach the 20 mL syringe to the valve of the Gas Pressure Sensor.
2. Set up the data-collection mode.
  - a. On the Meter screen, tap Mode. Change the mode to Events with Entry.
  - b. Enter the Name (Volume) and Units (mL). Select OK.
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.*

4. 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. 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. Tap Keep and enter **5.8**, the gas volume (in mL) on the screen. 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.

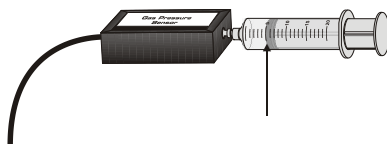


Figure 2

- d. Continue this procedure using syringe volumes of 10.0, 12.5, 15.0, 17.5, and 20.0 mL.
- e. Stop data collection.
5. 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.
6. 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. Choose Curve Fit from the Analyze menu.
  - b. Select Power as the Fit Equation. The curve fit statistics for these two data columns 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. Select OK.
7. (optional) If directed by your instructor, proceed directly to the Extension that follows Processing the Data.

## DATA AND CALCULATIONS

Volume (mL)	Pressure (kPa)	Constant, $k$ <u><math>P/V</math> (direct) or <math>P \cdot V</math> (inverse)</u>
5	110.	20 kPa/mL } 600 kPa·mL
10.	56	5.6 kPa/mL } 560 kPa·mL
12	42	3.5 kPa/mL } $5.0 \times 10^2$ kPa·mL
15	35	2.3 kPa/mL } 530 kPa·mL
17.5	30.	1.7 kPa/mL } 530 kPa·mL
20.	25	1.25 kPa/mL } $5.0 \times 10^2$ kPa·mL
* 40	??	

↑  
more consistent

## PROCESSING THE DATA

- If the volume is *doubled* from 5.0 mL to 10.0 mL, what does your data show happens to the pressure? Show the pressure values in your answer.
- If the volume is *halved* from 20.0 mL to 10.0 mL, what does your data show happens to the pressure? Show the pressure values in your answer.
- If the volume is *tripled* from 5.0 mL to 15.0 mL, what does your data show happened to the pressure? Show the pressure values in your answer.
- 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? Explain your answer.
- 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.  
 using the 20 mL data = 25 kPa &  $P \propto \frac{1}{V}$   
 40 mL  $P = \frac{1}{2}(25 \text{ kPa}) = \boxed{12.5 \text{ kPa}}$
- Based on your data, what would you expect the pressure to be if the volume of the syringe was decreased to 2.5 mL.
- What experimental factors are assumed to be constant in this experiment?  
 Temperature & moles constant
- 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.

### LabQuest 2A

9. 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. *m slope*
10. Using  $P$ ,  $V$ , and  $k$  write an equation representing Boyle's law. Write a verbal statement that correctly expresses Boyle's law. *u*

### 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 using LabQuest:
  - a. Tap the Table tab to display the data table.
  - b. Choose New Calculated Column from the Table menu.
  - c. Enter the Name (1/Volume) and Units (1/mL). Select the equation,  $A/X$ . Use Volume as the Column for  $X$ , and **1** as the value for  $A$ .
  - d. Select OK.
2. Follow this procedure to calculate regression statistics and to plot a best-fit regression line on your graph of pressure vs. 1/volume:
  - a. Choose Graph Options from the Graph menu.
  - b. Select Autoscale from 0 and select OK.
  - c. Choose Curve Fit from the Analyze menu.
  - d. Select Linear as the Fit Equation. 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.
  - e. Select OK. 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.
3. Draw a sketch of the two graphs:
  - a. Pressure (y-axis) vs Volume (x-axis)
  - b. Pressure (y-axis) vs 1/Volume (x-axis)

# Graphing Data as a way to find the relationship

Question:

Is the relationship between pressure & volume direct or inverse?

$\uparrow P \propto V \uparrow$  Direct relationship

$\uparrow P \propto \frac{1}{V} \downarrow$  Inverse relationship

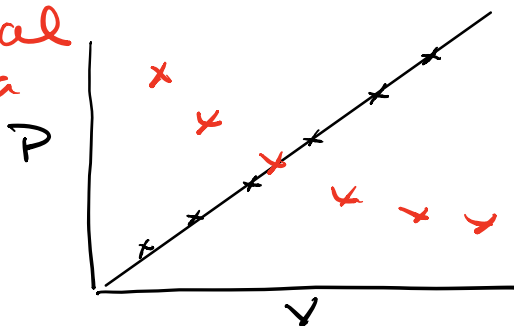
Direct Relationship ~~X~~

$$P \propto V$$

$$P = mV \quad | \quad m = \text{proportionality constant}$$

$$y = mx + b \quad m = \text{slope of line}$$

Actual Data



If we get a straight line  $\Rightarrow$  The relationship is direct

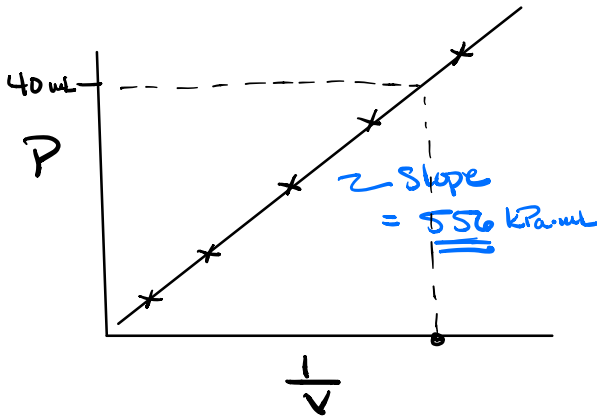
## For Inverse Relationship

$$P \propto \frac{1}{V}$$

$$P = m \frac{1}{V}$$

Correct ✓

$$y = m x + b$$



If the graph of  $P$  vs.  $\frac{1}{V}$  results in a straight line then the relationship is inversely proportional

$$(\checkmark) P = m \cdot \frac{1}{V} (\checkmark)$$

$$PV = m \leftarrow \begin{array}{l} \text{slope of line} \\ \text{Constant} \end{array}$$

Slope of line from graph

$$m = 556 \text{ kPa} \cdot \text{mL}$$

$$P = 556 \text{ kPa} \cdot \text{mL} \cdot \frac{1}{V}$$

$$P = 556 \text{ kPa} \cdot \text{mL} \cdot \frac{1}{40 \text{ mL}}$$

$$\boxed{P = 13.9 \text{ kPa}} = \boxed{P = 1.0 \times 10^1 \text{ kPa} \text{ to 1 sig fig}}$$



## Combined Gas Law

$$\frac{P_1 V_1}{n_1 T_1} = \frac{P_2 V_2}{n_2 T_2} \quad \left| \begin{array}{l} \text{if we hold Temp \&} \\ \text{moles Constant} \\ T_1 = T_2 \quad n_1 = n_2 \end{array} \right.$$

$$(\cancel{n_1 T_1}) \frac{P_1 V_1}{\cancel{n_1 T_1}} = \frac{P_2 V_2}{\cancel{n_1 T_1}} (\cancel{n_1 T_1})$$

$$P_1 V_1 = P_2 V_2 \quad \text{Boyle's Law}$$

$$(\checkmark). P = m \frac{1}{V} \cdot (\checkmark) \quad \text{Inverse Relationship}$$

$m = \underline{\underline{\text{Constant}}}$  Slope

$$P_1 V_1 = m$$

$$P_2 V_2 = m$$

$$P_1 V_1 = P_2 V_2 \quad \text{Boyle's Law}$$

Example from question #5  
we asked what is the pressure at 40 mL?

$$\text{Pressure}_1 = 25 \text{ kPa} \quad \text{Volume}_1 = 20 \text{ mL}$$

$$\text{Pressure}_2 = ? \text{ kPa} \quad \text{Volume}_2 = 40 \text{ mL}$$

$$\frac{P_1 V_1}{V_2} = \frac{P_2 V_1}{V_2}$$

$$P_2 = \frac{P_1 V_1}{V_2} = \frac{(25 \text{ kPa})(20 \text{ mL})}{(40 \text{ mL})} = 12.5 \text{ mL}$$

$$P_2 = \boxed{13 \text{ mL}}$$