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 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 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.
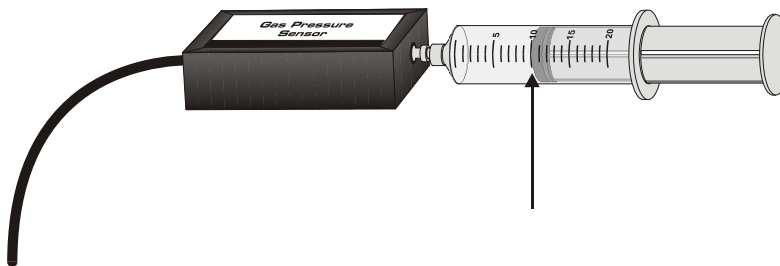

Figure 1

MATERIALS

TI-83 Plus or TI-84 Plus graphing calculator	Vernier Gas Pressure Sensor
EasyData application	20 mL gas syringe
data-collection interface	

PROCEDURE

1. Prepare the Pressure Sensor and an air sample for data collection.

    a. Turn on the calculator and connect it to the data-collection interface.
    b. Connect the Pressure Sensor to the interface.
    c. With the 20 mL syringe disconnected from the 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.
    d. Attach the 20 mL syringe to the valve of the Pressure Sensor with a gentle half-turn.

2. Set up EasyData for data collection.

    a. Start the EasyData application, if it is not already running.
    b. Select ⌈File⌉ from the Main screen, and then select **New** to reset the application.
    c. Select ⌈Setup⌉ from the Main screen, and then select **Events with Entry**.

3. You are now ready to collect pressure and volume data. It is best for one person to take care of the gas syringe and for another to operate the calculator.

   a. Select ⸤Start⸣ to begin 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 calculator screen stabilizes.

   c. Select ⸤Keep⸣ and enter **5**, the gas volume (in mL). Select ⸤OK⸣ to store this pressure-volume data pair.
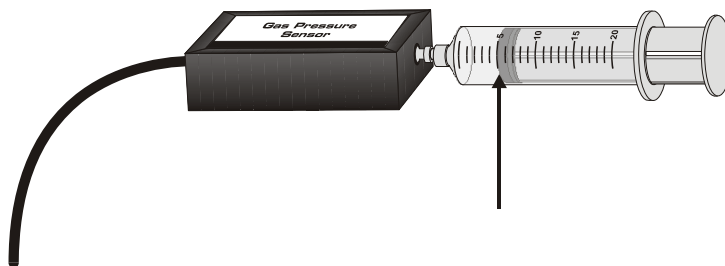

Figure 2

   d. To collect another data pair, move the syringe to 7.5 mL. When the pressure reading stabilizes, select ⸤Keep⸣, enter **7.5** as the volume, and select ⸤OK⸣ to store the data pair.

   e. Continue with this procedure using volumes of 10.0, 12.5, 15.0, 17.5, and 20.0 mL.

   f. Select ⸤Stop⸣ when you have finished collecting data.

4. Examine the data pairs on the displayed graph. As you move the cursor right or left, the volume (X) and pressure (Y) values of each data point are displayed above the graph. Record the pressure (round to the nearest 0.1 kPa) and volume data values in your data table.

5. 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. Select ⸤Anlyz⸣, then **Power Fit**. The linear-regression statistics for these two lists are displayed for the equation in the form

   $$y = ax^\wedge b$$

   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*.

   b. To display the regression curve on the graph of pressure *vs.* volume, select ⸤OK⸣. If you have correctly determined the mathematical relationship, the power regression line should very nearly *fit* the points on the graph (that is, pass through or near the plotted points).

6. (optional) Print a graph of pressure *vs.* volume, with a regression line displayed.

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 (P/V or P•V)

PROCESSING THE DATA

1. 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.

2. 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.

3. 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.

4. 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.

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.

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

8. 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.

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.

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 or volume^{-1}) may also be plotted. To do this using your calculator:

   a. From the Main screen, select [Quit], then [OK] to exit EasyData.
   b. Create a new data list, reciprocal of volume, based on your original volume data.
   c. To view the data lists, press [STAT] to display the EDIT menu, and then press [ENTER] to select Edit.
   d. Move the cursor up and to the right until the L3 heading is highlighted.
   e. Create a list of *1/volume* values in L3 by pressing [2nd] [L1] [χ^{-1}] [ENTER].

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. Restart EasyData.
   b. Select [Graph] to view the Graph screen.
   c. Select [Adv] and then select **L3 vs L2**. Note that L2 is pressure and L3 is 1/volume.
   d. Select [Anlyz], then **Linear Fit**. The linear-regression statistics for these two lists are displayed for the equation in the form:
   $$y = ax + b$$
   where *x* is 1/volume, *y* is pressure, *a* is a proportionality constant, and *b* is the y-intercept.
   e. To display the linear-regression curve on the graph of pressure *vs.* 1/volume, select [OK]. If the relationship between P and V is an inverse relationship, the plot of P versus 1/V 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. (optional) Print a copy of the graph of pressure *vs.* 1/volume, with the linear regression curve displayed.