21. Boyle's Law

Objectives

Students observe changes in pressures and volumes of gases as they apply to Boyle's Law. At the end of this lab, students:

- ♦ Understand the relationship between volume and pressure of an enclosed gas at constant temperature.
- ♦ Are able to graph this relationship and derive an equation relating pressure and volume of an enclosed gas
- ♦ Apply the equation to predict gas behavior using Boyle's Law

Procedural Overview

Students will gain experience conducting the following procedures:

- ♦ Decrease the volume of the gas in a closed system causing pressure to increase.
- ♦ Enclose gas with a 20ml syringe and pressure sensor and decrease the volume increasing pressure
- ♦ Linearization of data to determine the nature of a relationship between to variables.

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and activity	15 minutes
♦ Lab activity	20 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Absolute pressure sensor
- ♦ Barbed quick-release connector[1]
- ♦ Syringe[1], 20 mL
- ♦ Tubing[1]

[1] Included with PASCO Pressure Sensors

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Temperature, pressure, and volume of a gas
- Graphing Basics, including inverse and direct relationships

Related Labs in This Guide

Labs conceptually related to this one include:

- Temperature versus Heat
- Percent Oxygen in Air

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- Starting a new experiment with the data collection system �(1.2)
- Connecting a sensor to the data collection system �(2.1)
- Manual Sampling mode with manually entered data �(5.2.1)
- Starting a manually sample data set �(6.3.1)
- Recording a manually sampled data point �(6.3.2)
- Stopping a manually sampled data set �(6.3.3)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Changing the variable on the x- or y-axis �(7.1.9)
- Applying a curve fit �(9.5)
- Creating calculated data �(10.3)
- Saving data files �(11.1)

Background

If you take an isolated system like a Mylar® balloon filled with helium and place it in a cooler environment, it will contract. If you put it in the sun or blow hot air on it with a blow dryer, it will expand and rise due to its increased buoyancy. But what if you held the temperature constant? What changes if only pressure and volume vary while temperature isn't changed at all?

If you squeeze (decrease the volume of) an enclosed gas, the pressure of the gas increases. Boyle and his colleague Robert Hook built vacuum syringes to study the relationship between pressure and volume and found that at a constant temperature, the absolute pressure times the volume of the gas was always the same and can be represented as

$$PV = k \qquad \text{(Eq. 1)}$$

Another way of writing this relationship is:

$$P_1V_1 = P_2V_2 \qquad \text{(Eq. 2)}$$

Eq. 2 is related to the ideal gas law: $PV = nRT$ where n is the number of gas molecules, T is the temperature of the gas, and R is the ideal gas constant. If n and T are held constant, then nRT becomes a constant and the equation can be rewritten as Eq. 1 or Eq. 2: $P_1V_1 = P_2V_2$, which is the most fundamental of all the gas laws.

Pre-Lab Discussion and Activity

A great discussion about Boyle's Law starts with scuba divers. Scuba divers breathe atmospheric air from a canister that is a constant shape and volume, yet it must be filled up and does get empty after a while. How does air get inside a scuba tank? Through pressure, air is packed into the scuba tanks by a compressor, which takes in air from the atmosphere and forces it into the small canisters. Because all that air is crammed into a small space, it's under tremendous pressure. As the air is let out, it expands, and the pressure in the canister decreases as it empties.

1. What is the basic relationship stated in Boyle's Law?

Gas pressure is inversely related to its volume.

2. What mathematical relationship best represents Boyle's Law?

$PV = k$ or $P_1V_1 = P_2V_2$

3. If you double the volume, what would happen to the absolute pressure on an ideal gas?

It would be half the original pressure.

4. What if you decreased the volume to one half its original value?

The absolute pressure would double from its original value.

Connect an absolute pressure sensor to a syringe as you would for the experiment, and then connect the absolute pressure sensor to a data collection system set up to project Pressure to the class. Wrap your hand around the syringe, and show the change in pressure.

Remind the class that we want to observe the relationship between pressure and volume, so keep the system isothermal. Keep the syringe away from heat sources, and hold the syringe so that you are not changing its temperature.

Lab Preparation

Although this activity requires no specific lab preparation, allow 10 minutes to assemble the equipment needed to conduct the lab.

Safety

Add these important safety precautions to your normal laboratory procedures:

♦ To minimize the risk of injury or damage to the equipment, avoid over-compressing the air in the syringe.

Sequencing Challenge

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

3	2	4	1
Compress the gas in the syringe by pushing the plunger. Record the volume and pressure each time.	Configure the data collection system to measure pressure for various volumes.	Graph Pressure versus Volume for at least 6 data points. Determine the relationship between pressure and volume.	Connect a syringe to the absolute pressure sensor.

Procedure with Inquiry

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Note: Students use the following technical procedures in this activity. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

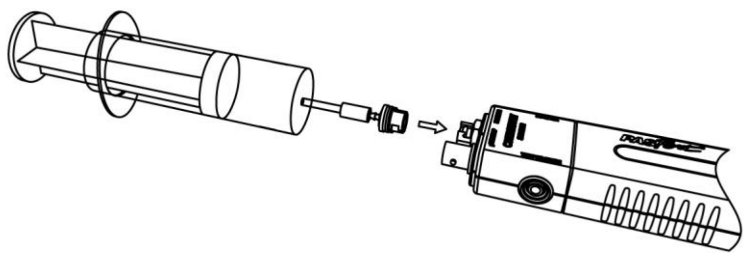
Set Up

1. ☐ Start a new experiment on the data collection system. �(1.2)

2. ☐ Connect the absolute pressure sensor to the data collection system. �(2.1)

3. ☐ Set up your data collection system to collect manually entered data in a table with Volume in mL as the user entered measurement. �(5.2.1)

4. ☐ Set the syringe to 20 mL, and connect it to the absolute pressure sensor using the shortest piece of tubing possible and the barbed quick-release connector.



Collect Data

5. ☐ Begin recording a set of manually sampled data starting with the plunger at 20 mL. �(6.3.1)

6. ☐ Record the first manually sampled data point at 20 mL. �(6.3.2)

7. ☐ Squeeze the plunger compressing the volume inside the syringe to 18 mL, then record the next manually sampled data point. �(6.3.2)

8. ☐ Repeat the previous step compressing the volume by an additional 2 mL each time until you have reached a final volume of 10 mL.

9. ☐ Stop recording data. �(6.3.3) Copy the values to Table 1 in the Data Analysis section.

Analyze Data

10. ☐ Use your data collection system to create a graph of Pressure versus Time. �(7.1.1)

11. ☐ Change the *x*-axis to the manually entered measurement Volume. �(7.1.9)

12. ☐ Sketch your graph of Pressure versus Volume in the Data Analysis section.

13. ☐ Look at your graph of Pressure versus. Volume. Is it a linear or curved relationship?

It's a curved relationship, so it's nonlinear.

14. ☐ What simple mathematical relationship do you think this type of curve represent?

The asymptotic curve shows an inverse relationship, where as the *x*-component gets large, the *y*-component goes to zero. Conversely, as the *x*-value goes to zero, the *y*-value goes to infinity.

15. ☐ Try applying different curve fits until you find the one that best represents the trend of the data. �(9.5)

16. ☐ Which curve fit best represented the data trend?

Inverse

17. ☐ How could you manipulate the data (by squaring, doubling, inverting, or taking the square root) to plot a new variable that would give a linear graph with pressure?

If you could plot Pressure versus (1 / Volume), it would yield a linear graph.

18. ☐ Create the following calculation: VolumeInv = 1/[volume] �(10.3)

19. ☐ Change the *x*-axis from Volume to VolumeInv on the graph of Pressure versus Volume on your data collection system. �(7.1.5)

20. ☐ Sketch your graph of Pressure versus VolumeInv in the Data Analysis section.

21. ☐ Apply a Linear curve fit to your plot of Pressure versus VolumeInv. �(9.5)

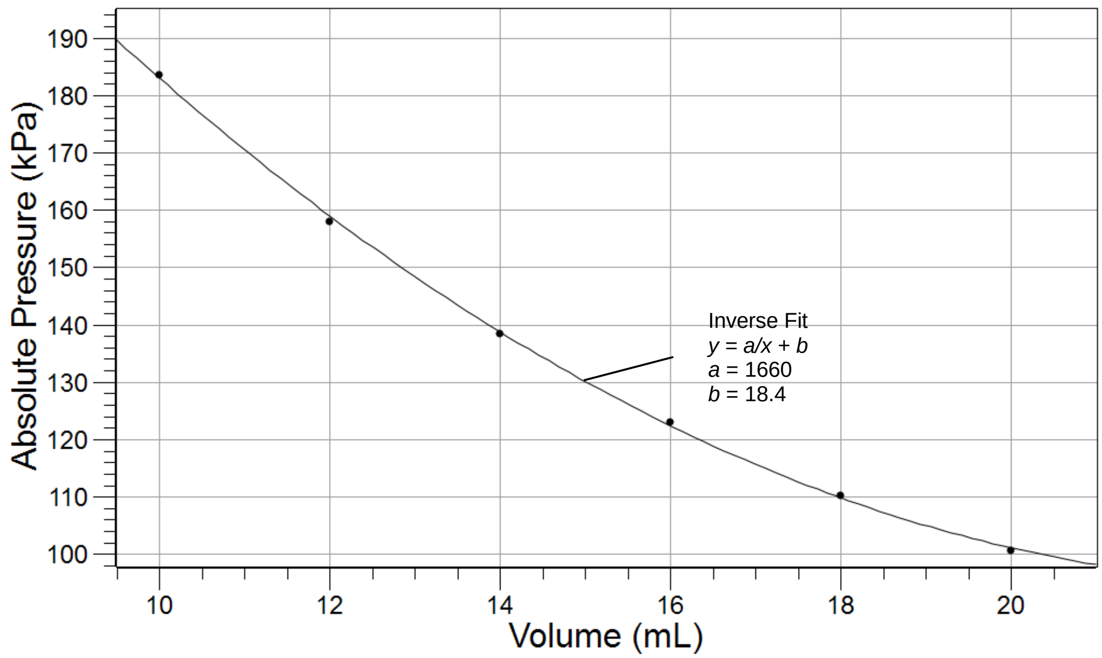
22. ☐ Save your experiment as instructed by your teacher. �(11.1)

Data Analysis

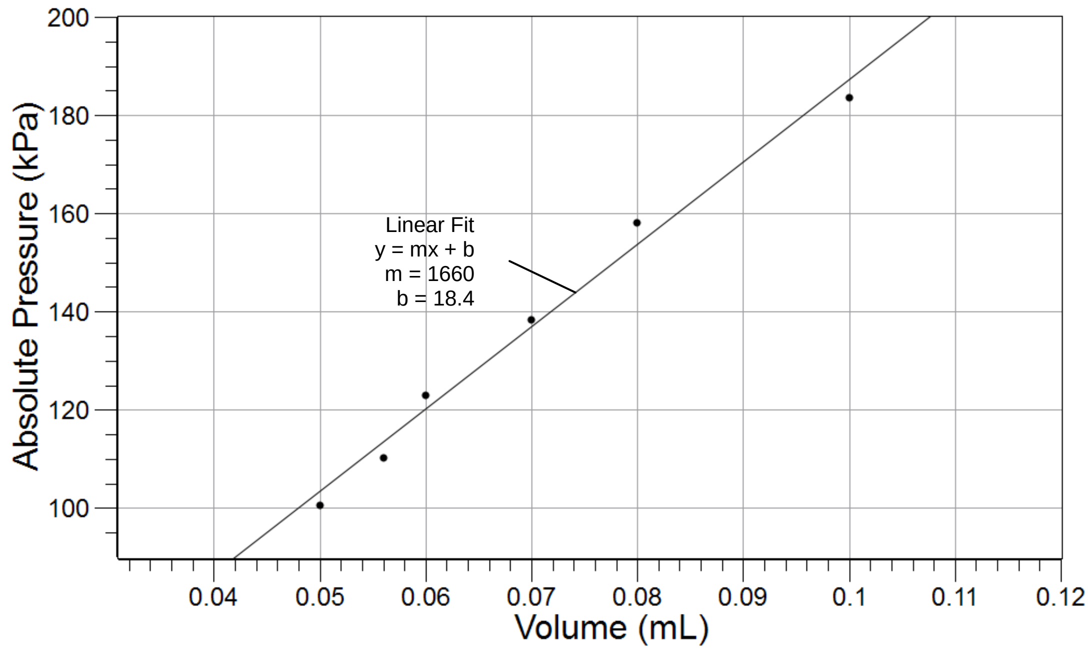
Table 1: Volume and pressure

Volume (mL)	Pressure (kPa)
20	100.62
18	110.30
16	123.02
14	138.36
12	158.00
10	183.56

Pressure versus Volume



Pressure versus 1/Volume



Analysis Questions

1. Look at your graph of Pressure versus VolumeInv. How well does the linear curve fit represent the trend of this data? What does this mean?

The linear curve fit strongly represents the trend of the data, which means the original data of Pressure versus Volume is an inverse relationship.

2. What does this mean in general for finding the mathematical relationship of different types of data plots?

A mathematical relationship can be applied to a data set, and if the resulting *x-y* plot is linear, then the mathematical relationship that was applied is a good representation of the trend of the original data plot.

3. How would you describe the relationship between Pressure and Volume in words?

Pressure is proportional to the inverse of volume.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Does the shape of the graph make sense, knowing the common behaviors of gases, volumes, and pressures? Explain why or why not.

The graph makes good sense. Squeezing the gas by applying force to the plunger of the syringe causes the volume to decrease, and the pressure of the gas to increase. Likewise, if a gas is allowed to expand, it will increase its volume so as to decrease its pressure.

2. Volume and pressure of an ideal enclosed gas at a constant temperature are inversely related. What happens if:

a. You cut the volume in half, what would happen to the absolute pressure?

It would double.

b. What if you cut the volume in half again, how would the final pressure relate to the original pressure before you first moved the syringe in part a) above?

It would be four times the original pressure.

3. The surrounding air pressure at high elevations (like in the mountains) is much less than at sea level. Explain how this affects the appearance of a sealed bag of potato chips that you take from sea level to high elevations.

The bag becomes noticeably larger in volume because of lower pressure on the outside of the bag. The pressure inside the bag is fixed, so less pressure on the outside means a higher volume for the bag.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. Boyle's Law states that, for an enclosed gas,

- **A.** Pressure is inversely related to volume.
- **B.** Pressure increases as volume increases.
- **C.** (Pressure × volume) equals a constant at a given temperature.
- **D.** Volume increases as temperature decreases.
- **E. Both A and C are correct.**

2. According to Boyle's Law, what must happen to the size of bubbles as they rise to the top of a carbonated beverage?

- **A.** The bubbles stay the same size.
- **B.** The bubbles expand as they rise because the pressure on them is greater.
- **C.** The bubbles contract as they rise because the pressure on them is greater.
- **D.** The bubbles contract as they rise because the pressure on them is lower.
- **E. The bubbles expand as they rise because the pressure on them is lower.**

3. A container of 2.5 Liters of air is under pressure of 85 kPa. What is its volume after the pressure is increased to 105 kPa?

- **A.** 0.494 L
- **B. 2.02 L**
- **C.** 3.09 L
- **D.** 0.324 L
- **E.** none of these

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. If a gas is enclosed and held at constant temperature, **Boyle's Law** states that the absolute pressure of the gas is **inversely** proportional to its volume. This means that if the number of gas particles is held **constant** at the same **temperature**, cutting the **volume** in half will double the pressure of the gas. Similarly, if the **pressure** were to be decreased by one-half the volume would have to expand to **double** its original amount.

2. Applications of Boyle's Law are all around us. Scuba divers have to **exhale** the air from their lungs as they **rise** to the surface of the water, because the air in their lungs **expands** greatly as the fluid pressure **decreases** when they near the surface. In fact, since one **atmosphere** of pressure represents the increase for every 10.3 meters of water depth, a scuba diver at a depth of about **21** meters would be at a pressure of 2 atmospheres. This means the air in his lungs would expand to about grow about **2 times** the volume if he did not exhale the air as he rose to the surface.

Extended Inquiry Suggestions

Instructors can follow this lab with a discussion of atmospheric pressure and sealed containers: what do sealed containers do when you take them from sea level to higher elevations? Mention how Boyle's Law leads quickly to Charles' Law, the volume-temperature law, and of course the ideal gas law. Be sure to list exceptions to the ideal gas law. Lastly, instructors can focus on the vast amount of scientific study going on at the time that Boyle published his work (with the assistance of Robert Hooke). French Physicist Edme Mariotte discovered the same gas law working independently of Boyle and Hooke just 4 years after Boyle published his work.

Instructors can quickly combine Boyle's Law with Charles' Law to get the combined gas law, and again combined with Avogadro's Law to get the ideal gas law. It is advantageous for both instructors and students to see Boyle's Law (and the other gas laws) present in the ideal gas law.