WARD'S DataHub
The Power of Twelve
The Convenience of One

# Boyle's Law: Registering the Pressure Changes of Gas Held in a Closed Container at a Constant Temperature, in Relation to Variations in Volume

*(Teacher's Guide)*

## OVERVIEW

Students will investigate the effect of volume changes on the pressure inside a syringe with a fixed amount of air at a constant temperature. They will measure the air pressure and then proceed to build a graph plotting their results in order to analyze them.

## MATERIALS NEEDED

Ward's DataHub
USB connector cable*
Luer-Lock syringe 60 mL
Plastic tube

** – The USB connector cable is not needed if you are using a Bluetooth enabled device.*

## NUMBER OF USES

This demonstration can be performed repeatedly.

# FRAMEWORK FOR K-12 SCIENCE EDUCATION © 2012

* The Dimension I practices listed below are called out as **bold** words throughout the activity.

| Dimension 1 Science and Engineering Practices | | | | |
|---|---|---|---|---|
| | ✓ | Asking questions (for science) and defining problems (for engineering) | ✓ | Use mathematics and computational thinking |
| | | Developing and using models | ✓ | Constructing explanations (for science) and designing solutions (for engineering) |
| | ✓ | Planning and carrying out investigations | | Engaging in argument from evidence |
| | ✓ | Analyzing and interpreting data | ✓ | Obtaining, evaluating, and communicating information |

| Dimension 2 Cross Cutting Concepts | | | | |
|---|---|---|---|---|
| | | Patterns | | Energy and matter: Flows, cycles, and conservation |
| | ✓ | Cause and effect: Mechanism and explanation | | Structure and function |
| | | Scale, proportion, and quantity | | Stability and change |
| | ✓ | Systems and system models | | |

| Dimension 3 Core Concepts | Discipline | Core Idea Focus |
|---|---|---|
| | Engineering, Technology, and Applications of Science | ETS2: Links Among Engineering, Technology, Science, and Society |
| | | ETS2.B: Influence of Engineering, Technology and Science on Society and the Natural World |
| | Physical Science | PS1: Matter and Its Interactions |
| | | PS1.A: Structure and Properties of Matter |
| | | PS2: Motion and Stability: Forces and Interactions |
| | | PS2.A: Forces and Motion |

| NGSS Standards | Middle School Standards Covered | High School Standards Covered |
|---|---|---|
| | MS.PS-SPM: Structure and Properties of Matter | HS.PS-SPM: Structure and Properties of Matter |
| | MS.PS-FM: Forces and Motion | HS.PS-FM: Forces and Motion |

# NATIONAL SCIENCE EDUCATION STANDARDS © 2002

| Content Standards (K-12) | | | |
|---|---|---|---|
| ✓ | Systems, order, and organization | | Evolution and equilibrium |
| ✓ | Evidence, models, and explanation | | Form and Function |
| ✓ | Constancy, change, and measurement | | |

| | Physical Science Standards Middle School | | Physical Science Standards High School |
|---|---|---|---|
| ✓ | Properties and Changes of Properties in Matter | | Structure of Atoms |
| | Motions and Forces | ✓ | Structure and Properties of Matter |
| | Transfer of Energy | | Chemical Reactions |
| | | | Motions and Forces |
| | | | Conservation of Energy and Increase in Disorder |
| | | ✓ | Interactions of Energy and Matter |

✓ Indicates Standards Covered in Activity

# LEARNING OBJECTIVES

**Core Objectives (National Standards):**

- Develop the ability to refine ill-defined questions and direct to phenomena that can be described, explained, or predicted through scientific means.
- Develop the ability to observe, measure accurately, identify and control variables.
- Decide what evidence can be used to support or refute a hypothesis.
- Gather, store, retrieve, and analyze data.
- Become confident at communicating methods, instructions, observations, and results with others.

**Activity Objectives:**

The purpose of this activity is to analyze the relationship between the pressure and volume of a confined gas at constant temperature, create a hypothesis and proceed to test it using the Ward's DataHub air pressure sensor.

**Time Requirement:**

45-60 minutes

# VOCABULARY

Air Pressure: The force exerted by air when compressed or confined in an area.

Barometer: An instrument for measuring atmospheric pressure.

Boyle's Law: At a constant temperature, the volume of a fixed amount of gas varies inversely with pressure on the gas.

Density: The degree of compactness of a substance.

Force: Simply a push or pull.

Gas Pressure: The number of pounds per square inch exerted by gaseous molecules.

Ideal Gas: A theoretical gas composed of a set of randomly-moving particles. At conditions such as STP (Standard Temperature & Pressure), most real gases behave like an ideal gas.

Universal Gas Constant: A constant that relates pressure, volume, temperature and number of moles of gas in an ideal gas law, 0.0821 (Latm/kmol)


**Teacher Notes**

**Balloon Test:**
**What happens when you change the volume of a gas?**

1. Hold the open end of a paper cup on the side of a partly inflated balloon.

2. Inflate the balloon until it presses against the cup and then let go of the cup. What happens?

Have your students use what they know about pressure and volume to write a hypothesis that explains the behavior of the cup after you let it go.

# INTRODUCTION

Throughout the history of science, many important scientists have devoted their work to the analysis and observation of natural phenomenon, and to its description through the development of mathematical formulas. Their conclusions have gradually passed into universal knowledge. For example, Avogadro, Gay-Lussac, Charles Graham and Robert Boyle studied the behavior of ideal gases between the 17th and 19th centuries. These eminent scientists contributed to the understanding of ideal gases, and established the relationships between the variables that describe them.

- **What variables do you think we should consider when studying the behavior of gases?**

- **Why do you think we talk about "ideal" gases?**

*Carry out the experiment with your class so that at the end, students will be able to answer the following question:*

- **What is the relationship between the pressure and volume of a confined gas?**

**DID YOU KNOW?**

Robert Boyle was born in 1627 to an aristocratic English family. He was a child prodigy who spoke Latin and Greek by the time he was eight years old. Boyle was one of the first scientists to rely on experimental observation to study the physical world, despite the fact that laboratory work was considered unimportant at the time. Boyle published a writing in which he argued that theories were no better than the experiments on which they were based. Gradually, his point of view was accepted and influential in the development of the modern scientific method. For this reason, he is often considered the founder of the modern scientific method.

# BACKGROUND

We define pressure as a force applied to a body on a unit area, i.e.,

$$P = \frac{F}{A}$$

Where P = pressure, F = force, and A = area.

Therefore, a gas confined to a small container will exert greater pressure upon the container walls, compared to a gas confined to a larger container. As the walls' surface area decreases the relationship between force/area becomes greater.

Robert Boyle and Edme Marriot studied this concept, presenting the Boyle-Marriot Ideal Gas Law. The study of general chemistry applies the ideal gas concept in referring to hypothetical gas composed of non-interacting point particles that move randomly. This approach is a simplified way of studying gases and allows us to predict their behavior. Boyle's Law states the inversely proportional relationship between the pressure and volume of an ideal gas at constant temperature. Therefore, the product of pressure and the volume is represented by a constant (k).

$$\mathbf{PV = k}$$

When we keep the temperature constant inside a closed system, with a fixed amount of gas, the before and after volume and pressure are represented by the following equation:

$$\mathbf{P_1 \times V_1 = P_2 \times V_2}$$

Where $P_1$ = Initial Pressure, $V_1$ = Initial Volume,
$P_2$ = Final Pressure, and $V_2$ = Final Volume

*At this point, encourage students to formulate a hypothesis to test as part of this activity. Students may find it helpful to formulate their hypothesis as an answer to the following question:*

- **If you have a confined gas inside a syringe and decrease the volume, how does the internal pressure change?**

# CONNECTING THE WARD'S DATAHUB TO A COMPUTER

**If you are using a Bluetooth communication device:**

Right-click on the Bluetooth icon in the lower right corner of the screen and select the Ward's DataHub you are using. The icon will change from gray to blue, as shown at right, indicating that the Ward's DataHub and the computer are now connected via Bluetooth.


**If you are using a USB communication device:**

In order to use USB communication, connect the Ward's DataHub and the computer with the USB cable supplied. Click on the USB icon at the lower right corner of the screen. This icon will change from gray to blue, as shown at right, indicating that the Ward's DataHub is connected to the computer via USB.

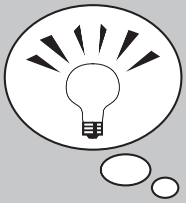

# USING THE WARD'S DATAHUB

= Select key = On/Off and Escape key = Scroll key

To collect measurements with the Ward's DataHub, it must first be configured as follows:

| | |
|---|---|
| 1. Turn on the Ward's DataHub by pressing the On/Off/Esc key. | |
| 2. Go to setup by using the Scroll key; then select Setup by pressing the Select key. | then |
| 3. Select the Set Sensors option by pressing the Select key. | |
| 4. If any sensor(s) appear on the screen, press the key representing that sensor to deactivate it. Once you have a blank screen, press the **Air Pressure Sensor** key once. |  |
| 5. Press the On/Off/Esc key once to return to the setup menu. | |
| 6. Press the Scroll key to highlight the Sampling Rate and then press the Select Key | then |
| 7. Press the Scroll key until "**Manual**" is highlighted, then press the Select key. | then |

| | |
|---|---|
| 8. Press the On/Off/Esc key to return to the setup menu. | |
| 9. Press the Scroll key to highlight the Number of Samples and then press the Select Key. | then |
| 10. Press the Scroll key until "**Manual**" is highlighted, then press the Select key. | then |
| 11. Press the On/Off/Esc key Three times to return to the main operating screen. | x 3 |
| 12. **Press the Select key to start measuring.** (You are collecting data when there is an icon of a Runner in the upper left hand corner of the screen.) | |
| 13. Once you have finished measuring, stop the Ward's DataHub by pressing the Select key, followed by the Scroll key. | then |



**DID YOU KNOW?**

Scuba divers breathe compressed air. A tank of air will last longer if the diver is 10 meters below the surface rather than 20 meters. Why is this? Ask students to think about Boyle's Law.

## ACTIVITY

1. Connect the syringe tip with the transparent head of the plastic tube and fill the syringe with air until 60 mL. Connect the plastic tube to the air pressure sensor screwing in the white head. Once completed, start the measurements.

2. Register the value of the pressure at a volume of 60 mL, then decrease the volume by 10 mL by gently pushing the plunger. Wait until the measurement stabilizes and register the pressure once again.

3. Measure the pressure at points of 60, 50, 40, and 30 mL of air inside the syringe and then stop the DataHub.

## RESULTS AND ANALYSIS

*The following steps explain how to analyze the experiment results.*

1. Connect the DataHub to the computer using the USB communication cable or via the Bluetooth wireless communication channel.

2. In the top menu, click on the  button, then select 

3. Select the last experiment on the list.

4. Observe the graph displayed on the screen.

5. Press the   button and write notes on the graph, specifying your observations according to the moment you registered the data.

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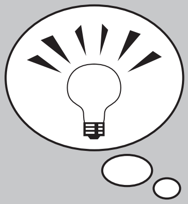


**DID YOU KNOW?**

Boyle's law applies to situations in which the volume of a gas is changed, then the pressure changes in the opposite way.

If you squeeze an inflated balloon, you are decreasing its volume. You should be able to feel the increased pressure of the gas inside it.

A bicycle pump works similarly. As you push on the plunger, the volume of air inside the pump gets smaller and the pressure increases.

## RESULTS AND ANALYSIS

*(continued)*

6. Press the  button, save the data to the computer and export to Excel.

7. Add a third column with the air volume (in mL) recorded at each measurement.

8. Multiply the air pressure with the volume in each case and compare the values.

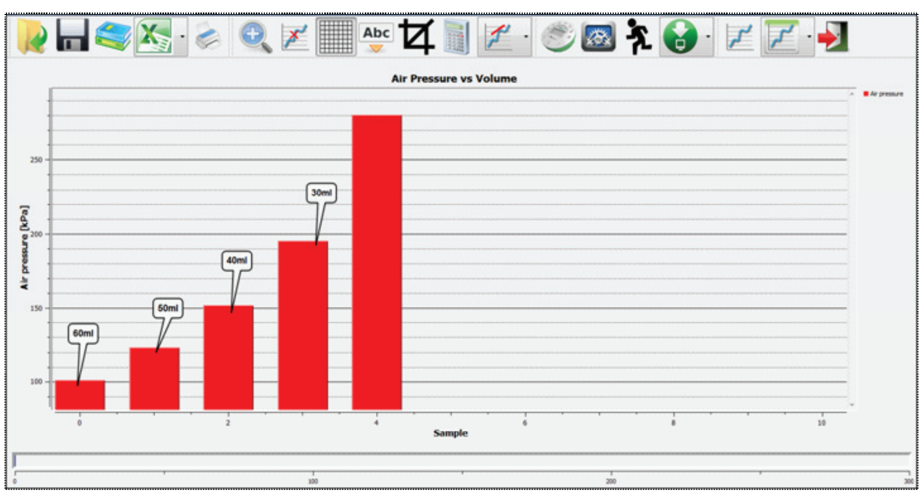
| | A | B | C | D |
|---|---|---|---|---|
| 1 | Time [s] | Air pressure [kPa] | Volum [ml] | Px V |
| 2 | 0 | 101.1 | 60 | 6066 |
| 3 | 1 | 123.2 | 50 | 6160 |
| 4 | 2 | 1[illegible] | [illegible]0 | 6080 |
| 5 | 3 | 195[illegible] | [illegible]0 | 5868 |

- **Were there differences between what you expected and what you actually observed?**

- **What happens to the air pressure when you decrease the volume?**

- **Can you find any relationship between the pressure and the volume of a gas in a closed container?**

*The graph below should be similar to the one the students obtained.*








For technical assistance, call WARD'S at 1-800-962-2660

## CONCLUSIONS AND ASSESSMENTS

1. What happens with the closed system's conditions when the volume is increased?

    *Students should establish that lifting the plunger raises the volume of the syringe, therefore lowering the pressure. This happens because the fixed number of air particles exerting force against the sides of the container has an increased available space.*

2. What kind of pressure variation is observed when the plunger is down?

    *Students should understand that when the plunger is down, the gas volume is decreased and therefore the pressure increases.*

3. When you observed the multiple of pressure per volume in each case, what do you notice about the values you obtained? **Explain.**

    *Students should observe and compare the values obtained on the data table and indicate that they are relatively constant; which is explained by the Boyle's Law Statement.*

4. If you consider the Boyle's Law Statement and observe the multiple of pressure and volume in each case, how do you **explain** the slight variation between them?

    *Students should indicate certain variations that could influence the results, such as the pulse of the person who was measuring, the accuracy of the syringe etc.*

5. What was the relationship between the volume and air pressure of the gas in a closed container?

    *Students should establish an inverse proportionality between the air pressure and volume. When the volume decreases, the pressure increases and vice versa.*

6. What do you think happens on a molecular level that allows these pressure variations to occur?

    *Students should relate the air pressure to the molecular movement of the air particles. The particles collide with other particles and with the walls of the container. At an increased volume there are fewer particles colliding in the same surface area, and therefore the pressure drops. If you reduce the space, the particles will collide more often, causing the pressure to rise.*

7. Write a concluding paragraph describing what you observed during the experiment.

    ***Students should reach the following conclusions:***

    *There is an inverse relationship between the volume and pressure inside a closed container. This relationship is expressed by the Boyle-Marriot Law, which tells us that at constant temperature the volume is inversely proportional to the pressure, and the product of both variables is constant. We can conclude from this that when you increase the volume, the pressure decreases; and when you decrease the volume the pressure increases.*

# ACTIVITIES FOR FURTHER APPLICATION

*The aim of this section is for students to extrapolate the knowledge acquired during this class and apply it to different contexts and situations. Furthermore, it is intended that students question and present possible explanations for the experimentally observed phenomena.*

1. Consider an ideal gas at an initial pressure $P_1$ of 1 atmosphere and a volume $V_1$ of 30 liters. What is the final volume if the pressure $P_2$ increases to 2.5 atm? Consider the temperature to be constant.

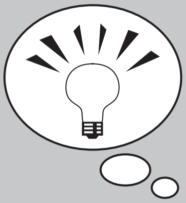
   *Students should put the Boyle-Marriot Law into practice and calculate the final volume $V_2$ of the ideal gas. The correct answer is 12 liters.*

2. What is the purpose of considering ideal as opposed to real gases?

   *Students should understand that a simple conceptual approach helps us to study and calculate the parameters of real gases behavior.*

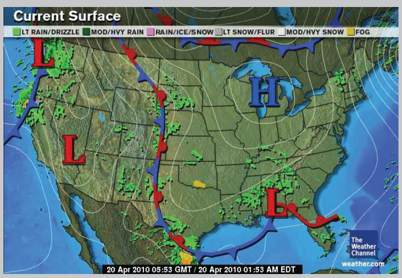
3. How would the pressure of a confined gas inside of a syringe vary if we tried to compress it as much as possible?

   *Students should analyze the situation and understand that if we compress the air, we reduce the volume, raising the pressure because of the inverse relationship of both variables.*



**DID YOU KNOW?**

Air pressure changes help predict local weather. Rising air pressure usually means fair weather. Falling air pressure generally means stormy weather.




**DID YOU KNOW?**

Boyle's Law plays an important role in research done with some high-altitude balloons. These balloons are made from lightweight plastic. They are filled with only a small fraction of the helium they could hold.
Why is that?

As a balloon rises through the atmosphere, the air pressure around it decreases steadily. As the air pressure decreases, the helium inside the balloon expands, stretching the balloon to a greater and greater volume. If the balloon were fully filled at takeoff, it would burst before it got very high.

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# Boyle's Law:
# Registering the Pressure Changes of Gas Held in a Closed Container at a Constant Temperature, in Relation to Variations in Volume
## *(Student Guide)*

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- **What variables do you think we should consider when studying the behavior of gases?**
- **Why do you think we talk about "ideal" gases?**

*After carrying out this experiment, you should be able to answer the following question:*

- **What is the relationship between the pressure and volume of a confined gas?**

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3. Select the last experiment on the list.
4. Observe the graph displayed on the screen.
5. Press the button and write notes on the graph, specifying your observations according to the moment you registered the data.
6. Press the button, save the data to the computer and export to Excel.
7. Add a third column with the air volume (in mL) recorded at each measurement.
8. Multiply the air pressure with the volume in each case and compare the values.

- **Were there differences between what you expected and what you actually observed?**

- **What happens to the air pressure when you decrease the volume?**

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# CONCLUSIONS AND ASSESSMENTS

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*(continued on next page)*

## CONCLUSIONS AND ASSESSMENTS

*(continued)*

5. What was the relationship between the volume and air pressure of the gas in a closed container?

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7. Write a concluding paragraph describing what you observed during the experiment.