# Boyle-Mariotte law

| | | |
|---|---|---|
| Physics | Mechanics | Mechanics of liquids & gases |
| Physics | Thermodynamics | Kinetic gas theory & gas laws |
| Chemistry | General Chemistry | Stoichiometry |

| Difficulty level | Group size | Preparation time | Execution time |
|---|---|---|---|
| easy | 1 | 10 minutes | 10 minutes |

This content can also be found online at:

http://localhost:1337/c/5fd8f4a3d6e75e00035e4d87

# Teacher information

## Application

Experimental setup for the investigation of Boyle-Marriote's law

The Boyle-Marriotte law is named after the physicists Robert Boyle and Edme Mariotte. They discovered the law independently of each other.

The law states that the pressure of an ideal gas at constant temperature and amount of substance is inversely proportional to its volume.

$$p \sim \frac{1}{V}$$

If you increase the pressure on an ideal gas, its volume is reduced. If you lower the pressure again, it expands.

$$p \cdot V = const. \qquad \frac{p_1}{p_2} = \frac{V_2}{V_1}$$



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## Application

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## Other teacher information (1/2)

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**Prior knowledge**

Students should have already learned basic pressure and volume.

**Scientific principle**

The principle developed in this experiment is also known as Boyle-Mariotte's law. It is based on the fact that the pressure exerted by an ideal gas at constant temperature is inversely proportional to its volume. In other words, the molecules of the gas repel each other more strongly at constant temperature when the volume is reduced.



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## Other teacher information (2/3)

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**Learning objective**

Using a U-tube made from a hose and glass tubing, have students prove that for a closed volume of gas, the product of pressure and volume is a constant.

**Tasks**

To do this, they are to measure the difference in height between the water levels when the prevailing pressure changes and illustrate the relationship by calculation and graphical representation.

## Other teacher information (3/3)

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### Notes

- Numerically, the air pressure in $hPa$ is equal to the specification in $mbar$. The indication in $hPa$ or $N/m^2$ corresponds to the SI system: $1\ Pa = 1\ N/m^2$.
- The result $p \cdot V = const.$, the statement of Boyle-Mariotte's law, is only valid at constant temperature (e.g. constant room temperature).
- The height difference to the floor must be used in both cases. Only then do the pressure and volume changes become large enough to really prove Boyle-Mariotte's law.
- The atmospheric pressure $p_0$ should be read by the students themselves from an existing barometer or given by the teacher. If both are not possible, the value of $p_0 = 1013\ hPa$ can be specified.



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## Safety instructions

The general instructions for safe experimentation in science lessons apply to this experiment.

# Student Information



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# Motivation

Bicycle front tyre

To inflate a tire on your bike, you fill the tube of the tire with air using a pump. This tube has a certain maximum volume and at a certain point it becomes noticeably more difficult to pump more air into the tyre, as the pressure in the tyre continues to rise. The pressure increases because the volume of the tube is limited and the air must be compressed. Before this, however, the volume in the pump must be compressed so strongly that the current pressure in the tube behind the valve is exceeded.

In this experiment you will investigate the relationship between the pressure and the volume of a gas.



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# Equipment

| Position | Material | Item No. | Quantity |
|---|---|---|---|
| 1 | Support base, variable | 02001-00 | 1 |
| 2 | Support rod, l = 600 mm, d = 10 mm, split in 2 rods with screw threads | 02035-00 | 1 |
| 3 | Support rod, stainless steel, l = 250 mm, d = 10 mm | 02031-00 | 1 |
| 4 | Glass tubes,l.250 mm, pkg.of 10 | 36701-68 | 1 |
| 5 | PVC tubing, inner dia. = 7 mm, l = 1 m | 03985-00 | 2 |
| 6 | Glass tube holder with tape measure clamp | 05961-00 | 1 |
| 7 | Beaker, 100 ml, plastic (PP) | 36011-01 | 1 |
| 8 | Syringe 20ml, Luer, 100 pcs | 02591-10 | 1 |
| 9 | Nozzle for glass screwthread | 43903-01 | 1 |
| 10 | Measuring tape, l = 2 m | 09936-00 | 1 |
| 11 | Vernier calliper, plastic | 03011-00 | 1 |



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## Set-up (1/4)

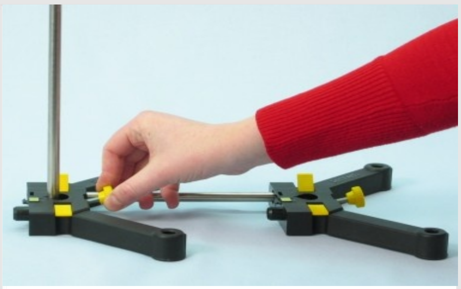
Connect the two halves of the support base with the 250 mm long support rod and fix them.

Screw together the split 600 mm long support rod.

Place the 600 mm long support rod in the front half of the support base and screw it tight.

Assembling the support base

Screwing the support rods



Fastening with the aid of the screw plug



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## Set-up (2/4)

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Attach the glass tube holder to the support rod

Clamp the glass tube holder to the long support rod.

Then clamp the measuring tape into the glass tube holder.

Attach the measuring tape to the glass tube holder

## Set-up (3/4)

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Structure of a U-tube

Build a U-tube with the glass tubes and the silicone tubing. The tube length should be more than 1.5 m.

- Attach the U-tube as high as possible to the support pole.
- If necessary, use some glycerine to connect the glass tubes to the tubing.

Using a syringe, fill the U-tube with water (without the plunger, as a funnel) until the two glass tubes are half full.

Fill U-pipe with water



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## Set-up (4/4)

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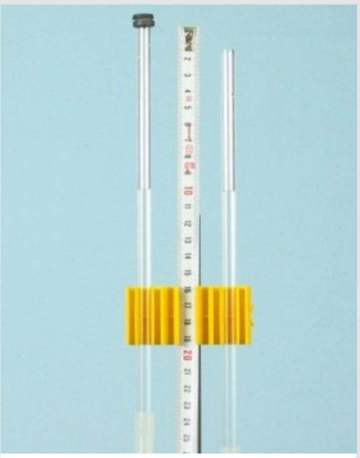

Place the rubber cap on the U-tube

Firmly place a rubber cap on the left glass tube.

Adjust the U-tube so that the water in both legs is at the same level again.

Mark the water level in the left glass tube with a felt-tip pen.

Marking the water level

## Procedure (1/3)

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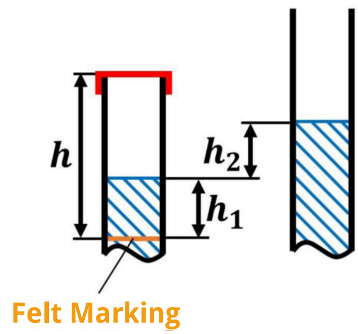
Measuring the inner diameter $d_i$

- Measure the inner diameter of the glass tubes with the caliper gauge $d_i$.
- Measure the air pressure $p_0$ or have your teacher give it to you. If necessary, use $p_0 = 1013\,hPa$.
- Measure the height $h$ of the air column above the mark in the left glass tube.
- Record the measured values in the log.




Measuring the height $h$ of the air column



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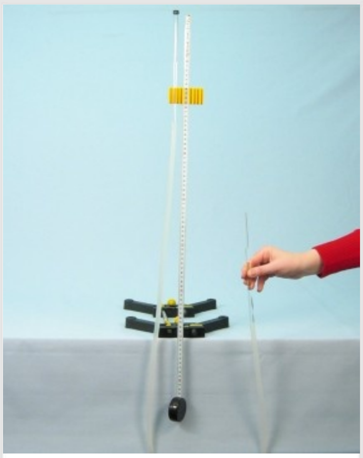
## Procedure (2/3)



Lowering the right glass tube

Pressure reduction in the closed volume:

- Take the right glass tube out of the holder and gradually lower it to the floor.
- Note for each height $h_1$ (distance of the water level in the left glass tube from the mark) the height $h_2$ (distance between the water levels in the right and left glass tubes).
- Measure 6 pairs of values and record them in Table 2 in the protocol.

## Procedure (3/3)

Lowering the left glass tube

Pressure increase in the closed volume:

- Fix the right glass tube back in the holder, take out the left one and lower it step by step like the right one before, down to the floor.
- Note again for each height $h_1$ (distance of the water level in the left glass tube from the mark) the height $h_2$ (distance between the water levels in the right and left glass tubes).
- Again, measure 6 pairs of values and record them in Table 3 in the protocol.



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# Report

## Table 1

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First, write down your measurement for the experimental constants in the adjacent boxes.

$h =$

$d_i =$ n

$p_0 =$ Pa

Notes to Table 2 & 3:

Calculate the volume $V$ of the enclosed gas volume according to:

$$V = \pi \cdot r^2 \cdot (h \pm h_1) \quad \text{with} \ \ r = \frac{d_i}{2}$$

($+$ for pressure reduction, $-$ for pressure increase)

Calculate the pressure $p$ in the sealed gas volume according to:

$$p = p_0 \mp h_2 \cdot g \cdot \rho \quad \text{with} \ g = 9.81 \, \frac{m}{s^2}, \ \rho = 1 \, \frac{g}{cm^3}$$

($-$ for pressure reduction, $+$ for pressure increase)



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## Table 2 (Pressure reduction)

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| $h_1\ [cm]$ | $h_2\ [cm]$ | $V\ [cm^3]$ | $p\ [hPa]$ | $p \cdot V\ [hPa \cdot cm^3]$ |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

Write down your measurements for the part of the experiment with the reduction in pressure in the adjacent table.

Calculate the corresponding pressures and volumes. Determine for each pair of measured values the product $p \cdot V$ and complete the table with it.

## Table 3 (Pressure increase)

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| $h_1\ [cm]$ | $h_2\ [cm]$ | $V\ [cm^3]$ | $p\ [hPa]$ | $p \cdot V\ [hPa \cdot cm^3]$ |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

Note down your measurements for the part of the experiment with the pressure increase in the table opposite.

Calculate the corresponding pressures and volumes. Determine for each pair of measured values the product $p \cdot V$ and complete the table with it.



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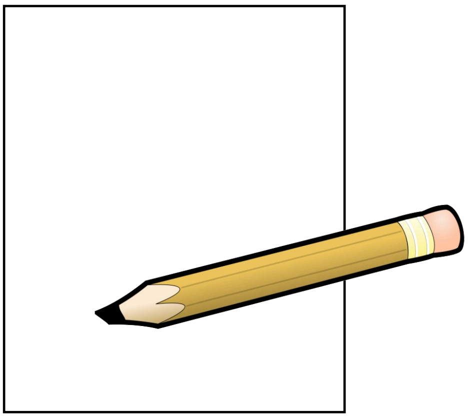
## Task 1



Now take a sheet of paper and create a diagram on it.

In this diagram the pressure $p$ ($y$-axis) as a function of the volume $V$ ($x$-axis) can be displayed.

## Task 2

Consider the shape of the resulting curve for the diagram of the pairs of values from pressure $p$ and volume $V$. What kind of function can this curve be described as?

- A parabolic function.
- A linear function.
- A constant function.
- An exponential function.

Check



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## Task 3

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Consider the values for $p \cdot V$ in Tables 2 and 3, what can you determine?

- ○ The products of $p$ and $V$ are always the same.
- ○ The products of $p$ and $V$ are steadily decreasing.
- ○ The products of $p$ and $V$ are steadily increasing.

Check

## Task 4

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Give the relationship between $p$ and $V$ in a formula.

- ○ $p \cdot V = const.$
- ○ $p \cdot V = \rho \cdot g \cdot h$
- ○ $p \cdot V = m \cdot g \cdot h$

Check



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# Task 5

The temperature was not changed in this experiment. What other relationship can you derive from the previous task for a closed volume filled with gas?

- [ ] $p_1/p_2 = V_2/V_1$
- [ ] $p \sim 1/V$
- [ ] $p_1/p_2 = V_1/V_2$

Check



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