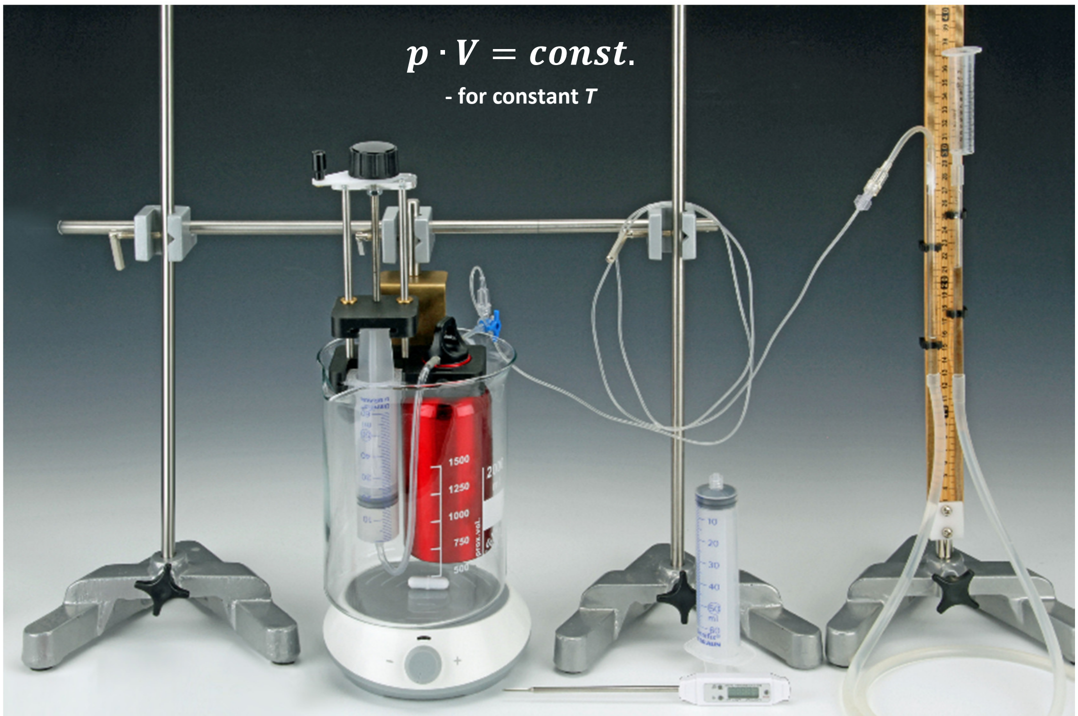
Boyle's law

Experiment number	132220-EN	*Topic*	Thermodynamic, gas laws				
Version	2019-01-02 / HS	*Type*	Student exercise	*Suggested for*	grade 12+	*p.*	1/4



Objective

To demonstrate that in a gas with a fixed temperature, the volume is inversely proportional with the pressure.

Principle

We investigate a fixed amount of atmospheric air. Part of the air is in a plastic syringe that is controlled via a spindle with a crank.

The pressure is measured with a liquid manometer. To keep the volume constant in the rest of the gas, the manometer branches are adjusted manually to keep the liquid level of the inner branch at a fixed point in the tube.

Equipment

(Detailed equipment list on the last page.)

Gas law apparatus

Beaker (dispensable)
Thermometer (dispensable)
Magnetic stirrer (dispensable)

Stand material

The liquid manometer

The manometer measures pressure difference relative to the atmosphere – *remember to measure the current barometric pressure as well* (or find it on the net).

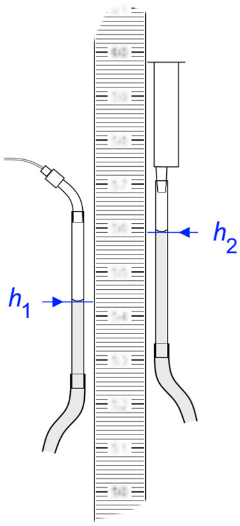
The pressure difference Δp is

$$\Delta p = \rho_W \cdot g \cdot (h_2 - h_1) \ ,$$

Where ρ_W is the density of water, g is the acceleration due to gravity and h_1 and h_2 are the liquid levels.

A small zero offset is possible if the two tubes haven't exactly the same inner diameter (due to capillarity).

Read h_1 and h_2 with both branches open to the atmosphere in order to correct the calculations later.



Designations

The *inner branch* of the manometer is the one with the same pressure as within the aluminium flask – its level is h_1 cf. the drawing on p. 1.

The *outer branch* is the one ending in the overflow vessel. In this branch, the pressure is the same as outside the apparatus (i.e. the barometric pressure).

Important precautions (read this first)

Measurements are made with normal, dry air.

It is therefore important to keep the aluminium flask free from liquid water as the saturated water vapour will ruin the precision. (The humidity in indoor air is normally so low that it is unimportant.)

The *water used in the manometer must also be kept away from the connection hose*. The hose is so thin that the strong capillary forces will make it difficult to get the water out again.

When the volume changes, the pressure will change as well. Therefore, one of the experiment team members must constantly assure that the liquid level in the inner branch is approx. at the centre of the glass tube by moving the manometer branches up and down.

Preparations

Set up the equipment as shown on p. 1 – wait to connect the connection hose to the manometer.

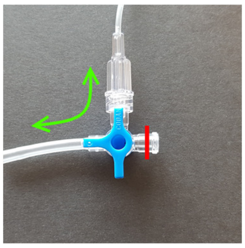
Use a thin permanent pen to make a horizontal line halfway up the glass tube in the inner branch. The liquid level must have this height, every time the pressure is measured.

Fill the manometer with demineralized water using a squeeze bottle – avoid air bubbles in the manometer hose and the glass tubes. The ideal amount of water will make the water reach the centre of both glass tubes. (Should the water level in the outer branch be a couple of centimetres higher or lower, it is still OK.)

You can squeeze the manometer hose slightly a few times to moisten the inside of the tubes around the readout positions.

Adjust the volume of the plastic syringe to **25 mL**.

Connect the manometer to the rest of the setup, and turn the three-way valve this way:



If you want to be completely sure to keep the temperature in the gas constant, you can place the aluminium flask and the syringe in the beaker and fill it up with water having room temperature.

Procedure

Turn the spindle to reduce the volume of the syringe to 0 mL. Remember to move the manometer branches to keep the water level in the glass tubes.

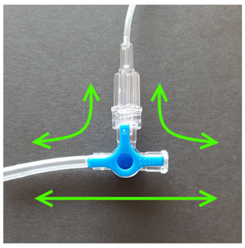
Wait about a minute to let the temperature stabilize.

Fine tune the manometer branches to place the water level in the inner branch exactly at the mark.

Read h_1 and h_2.

Increase the volume in 5 mL steps and repeat the measurement procedure for each new volume.

Turn the three-way valve so it is open to the atmosphere – it is OK if the water flows into the overflow vessel, but follow up by adjusting the branches of the manometer until they have the same height,



This eliminates the risk that the water is sucked into the connection hose.

If you've got time, you can repeat the measurement series of with a larger amount of air than before.

With the three-way valve open to the atmosphere, adjust the volume of the syringe to **45 mL**.

Turn the valve again to have a connection between manometer and the rest of the apparatus, but closed to the atmosphere.

Repeat the procedure above, but be careful with the initial reduction of the volume – the manometer will put a limit on how far down you can go.

Conclude again by opening to the atmosphere and placing the manometer branches at the same level.

If you still have time to spare, you can make the measurements yet another time but with a smaller amount of gas. This time the volume should be adjusted to **5 mL** before closing the valve and repeating the measurements.

Clean-up

If you used the beaker, it must be emptied after all measurements have been done. There will also be some water above the piston in the syringe which should also be emptied out.

Remove the water from the manometer hose.

Don't separate the manometer hose from the glass tubes, but remove the glass tubes from the plastic holders on the ruler.

Take off the plastic holders also to prevent them from getting slack. Put them in a plastic bag so they do not get lost.

Calibration of volumes

(*Only* to be performed if you are instructed to do so.)

Using precise digital scales, the volume of the different parts of the equipment can be measured. It requires you to fill up the part in question with water with a known temperature. The volume is then found from a table value for the density of water at this tempera-ture.

Note that the scale of the syringe cannot be assumed to be exact! If you find a deviation here, you must add a column for the corrected volume in the table used for the calculations.

The thickest hose parts are easiest measured with a caliper gauge.

For the volume of the thin connection hose, use the nominal value from the manual (uncertainties in this value only affect the sum of volumes slightly).

It is very important that all parts are thoroughly dry before the apparatus is used again, so make sure that it is not assembled with even a small amount of water inside. (Follow your teacher's instructions.)

Theory

R. Boyle and E. Mariotte proposed in 1662, resp. 1676, independently the relationship between pressure p and volume V for an amount of gas with constant temperature:

$$p \cdot V = const.$$

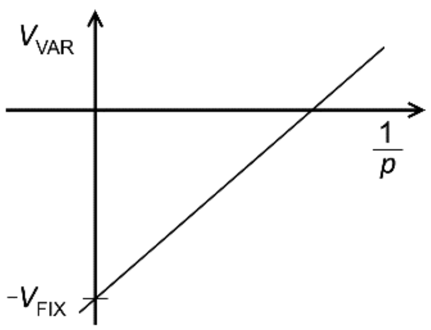
In the equipment used in this experiment, only part of the volume is variable: the volume of the syringe. Splitting In a fixed and a variable volume, we get:

$$V = V_{\mathrm{FIX}} + V_{\mathrm{VAR}} \quad ,$$

and is able to re-write Boyle's law to the following:

$$V_{\mathrm{VAR}} = const.\cdot \left(\frac{1}{p}\right) - V_{\mathrm{FIX}}$$

We find that there is a linear relationship between the entities $1/p$ and V_{VAR}. Graphically, it look like this:



Calculations

Convert the barometric pressure to Pa.

Make a table (e.g. a spreadsheet) for the measure-ments and calculations:

Barometric pressure				*Acceleration due to gravity*		
B =		Pa		g =		m s^{-2}
Offset correction				*Density of water*		
Δh_0 =		m		ϱ_V =		kg m^{-3}
V_{VAR}	h_1	h_2	Δh	Δh_{CORR}	Δp	p
mL	m	m	m	m	Pa	Pa

Here, Δh is the height difference $h_2 - h_1$.
Δh_0 is the value of $h_2 - h_1$ at pressure difference zero.
Δh_{CORR} is the corrected height difference $\Delta h - \Delta h_0$.

Δp is the pressure difference between the gas and the atmosphere.
p is the absolute pressure of the gas.

(It is not necessary to convert volumes to SI units – but it is OK to do so.)

Plot the volume as a function of the reciprocal of the pressure in a coordinate system big enough to extend the graph until it intersects the V axis.

If you completed more than one measurement series, plot each series separately, but in the same coordinate system.

Discussion and evaluation

How did you expect the graph(s) to look? Compare with the actual results.

If you didn't perform a measurement of the different partial volumes, you can used an expected value for V_{FIX} of about 430 mL. (This can vary a little bit.)

How do your experimental value for the fixed volume (from Boyle´s law) compare to the expected one?

Teacher's notes

Concepts used

Density
Pressure

Mathematical skills

Evaluation of expressions
Unit conversions
Graphs

About the equipment

Details about the gas law apparatus can be found in the equipment manual. Here you'll find e.g. nominal values for the volumes of the different parts of the apparatus.

If you by accident get water into the thin connection hose:
First, rinse the tube with 1 – 2 mL 96 % ethanol using the extra syringe with Luer Lock. Ethanol evaporates much easier than water.
Next, use the syringe to blow air through the hose several times – in *one* direction – while you spin the free end of the hose fast around in a circle. This is in order to throw off the droplets that otherwise would creep back into the hose due to capillarity.

In case water gets into the aluminium flask (e.g. if you want to calibrate the volume), it must be disassembled and dried internally. As it is impossible to check from the outside, it may be a good idea to do this every time the equipment has been used in a student exercise.

When assembling the apparatus again, you can use a tiny amount of vacuum grease on both sides of the gasket.

Connection with other experiments

You can make a mini project out of the three experiments with the gas laws:

132220	Boyle's law
132230	Absolute zero (Gay-Lussac's law)
132240	Charles' law

If performed in this order, the results from Boyle's law (the fixed volume V_{FIX}) can be used in Charles' law.

Thus you have two different methods (Gay-Lussac's law and Charles' law) for determining the absolute zero.

Names of the laws

Historically, these gas laws are connected to several physicists. Depending on tradition and language region, the same law can go under different names.

Detailed equipment list

Specifically for the experiment

180700	Gas law apparatus
007560	Beaker, 2 L, Duran, Low form [1])
064045	Magnetic stirrer 300-2000 rpm [1]) [2])

Standard lab equipment

062100	Digital thermometer [1])
000100	Stand base (3 pcs.)
000840	Stand rod (3 pcs.)
002310	Bosshead (3 pcs.)

Consumables

890300-6	Demineralised water
042300	vacuum grease

[1]) The experiment may be performed without these. (They are needed for the other two gas laws.)

[2]) This comes with a Euro plug. 064046 has a UK plug.