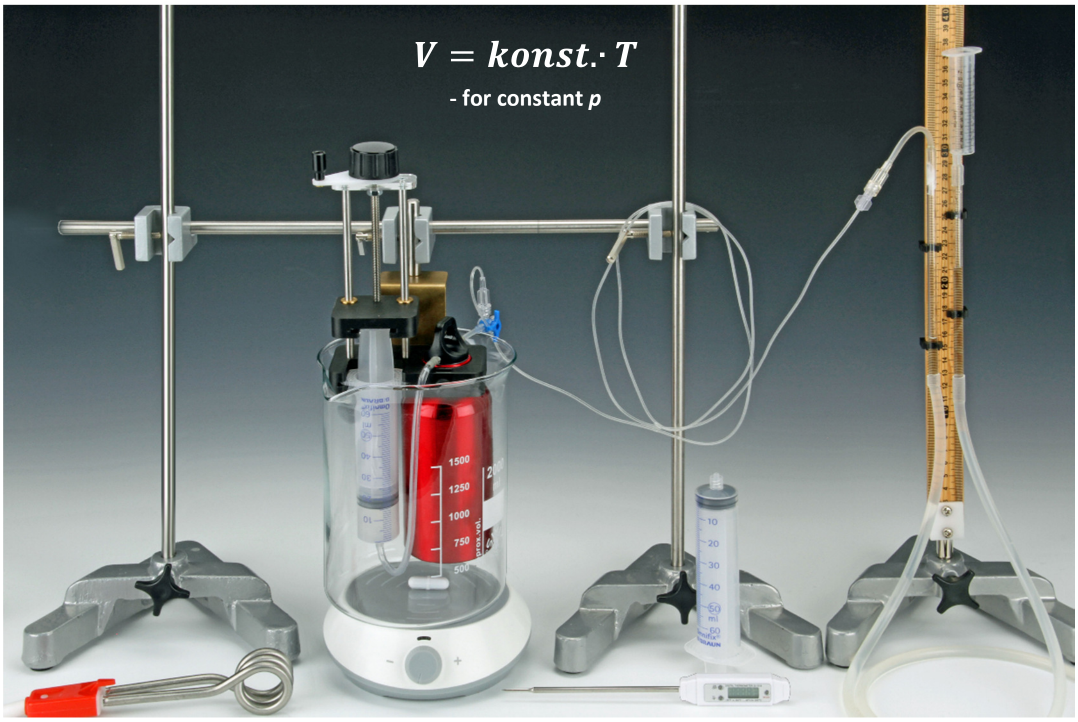
Charles' law

Experiment number 132240-EN	*Topic*	Thermodynamics, gas laws			
Version 2019-01-02 / HS	*Type*	Student exercise	*Suggested for* grade 12+	*p.*	1/4



Objective
To demonstrate that the volume of a gas with a constant pressure increases linearly with temperature. By extrapolating to zero volume, the absolute zero is found.

Principle
We investigate a fixed amount of atmospheric air with a temperature that is controlled by a water bath. Part of the air is contained in a plastic syringe, controlled with a spindle and a crank.

The pressure is measured with a liquid manometer. The liquid level in the manometer branches are kept at the same positions.

Equipment
(Detailed equipment list on the last page)

Gas law apparatus

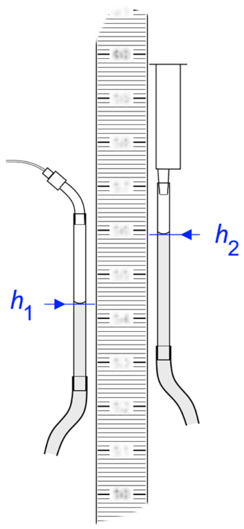
Beaker
Immersion heater
Thermometer
Magnetic stirrer

Stand material

Liquid manometer
The manometer measures pressure difference relative to the atmosphere. If you wish to know the absolute pressure, you must therefore know the barometric pressure.

In this experiment we only use the manometer to ensure that the pressure is constant, i.e. that the difference in liquid heights h_1 and h_2 is kept constant.

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



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 temperature changes, the gas will expand or contract. 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 adjusting the volume in the syringe.

If it is about to go wrong, it may be faster to temporarily lower the outer branch of the manometer.

Preparations

Set up the equipment as shown on p. 1 – wait to connect the connection hose to the manometer. Lower the aluminium flask as far into the beaker as possible – while still allowing the stirrer magnet to rotate.

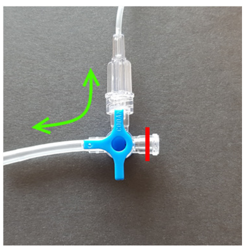
Use a thin permanent pen to make a horizontal line halfway up the glass tube in the inner branch. The liquid level must have this height, every time the pressure is measured. Place the tube on the ruler with the line at 500 mm.

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.

Move the outer manometer branch until h_1 = 500 mm (right at the marker line).

Adjust the syringe to **25 mL**.



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

Now the gas is confined inside the system.

Procedure

After closing the valve, adjust the syringe volume to **0 mL**. This will force the water in the manometer partly up into the overflow vessel.

Next, the air is cooled down.

Fill up the beaker with water as cold as possible – possibly from the fridge. However, after reaching equilibrium, the temperature must still be at least 8 - 10 °C.

The water must cover the aluminium flask and the plastic syringe completely.

Turn on the magnetic stirrer. Place the thermometer in the water. Wait 2 to 3 minutes.

Adjust the volume to place the water in the inner tube surface precisely at the marking line.

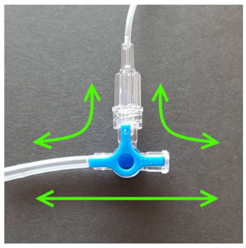
Write down the temperature and the syringe volume.

With the immersion heater, heat the water 5 – 10 degrees up. Turn off in time to prevent the temperature from rising too much.

Wait again a few minutes to let the temperature stabilize, adjust once more the volume, and repeat the measurement of volume and temperature.

Continue with other temperatures – as long as the piston in the syringe is within the scale.

Turn the three-way valve to open up to the atmosphere – to prevent the water from being sucked into the connection hose when the temperature drops.



Clean-up

With all measurements completed, the beaker must be emptied.

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.

There will be some water above the piston in the syringe which should also be emptied out.

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 temperature.

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

According to Charles' law, the volume of an amount of gas with constant pressure is proportional with the absolute temperature:

$$V = \text{const.} \cdot T$$

Mathematically speaking, the volume shrinks to 0 at T=0. (In reality, the relationship only holds as long as the temperature of the gas is somewhat higher than its liquefaction temperature.)

The volume of the gas is the sum of the (variable) volume of the syringe V_{VAR} and a larger, fixed volume V_{FIX}:

$$V = V_{\text{FIX}} + V_{\text{VAR}}$$

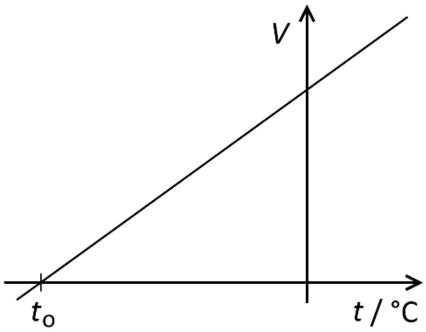
V_{FIX} can be found in three ways:

1. In the manual for the gas law apparatus, a nominal value is given, which is however subject to some uncertainty.
2. The volume can be found as described above (*Calibration of volumes*).
3. If you have performed experiment 132220 Boyle's law, one of the results is V_{FIX}.

When the temperature is measured in degree Celsius, the relation is no longer a proportionality, but a linear function:

$$V = const. \cdot t + V_0$$

Absolute zero t_0 (measured in °C) is found by determining the intersection between the graph and the t axis. (Consider why.)



Calculations

Make a table (e.g. a spreadsheet) for the measurements and calculations:

Fixed volumen		
V_{FIX} =		mL

t	V_{VAR}	V
°C	mL	mL

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

Plot the total volume $V = V_{\text{FIX}} + V_{\text{VAR}}$ as a function of temperature in a coordinate system big enough to extend the graph until it intersects the t axis. If you use a spreadsheet, you can instead calculate the intersection form the equation of a trend line through the data points.

Discussion and evaluation

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

Compare the measured t_0 with the table value for absolute zero.

A small amount of the gas doesn't have the same temperature as the rest – where in the apparatus is that positioned?

If we assume that this amount of gas stays at room temperature and has the same pressure as the rest of the gas, its volume is also fixed – in other words, it is a completely inactive part of the system. If we subtract this volume from V_{FIX}, what will be the consequence for the measured value of t_0?

(Try to get this volume from the equipment manual.)

Teacher's notes

Concepts used

Kelvin scale
Celsius scale
Pressure
(Density)

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
275010	Immersion heater, 300 W / 230 V [1])
064045	Magnetic stirrer 300-2000 rpm [2])

Standard lab equipment

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

Consumables

890300-6	Demineralised water
042300	vacuum grease

[1]) We can only provide this with a SHUKO plug.

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