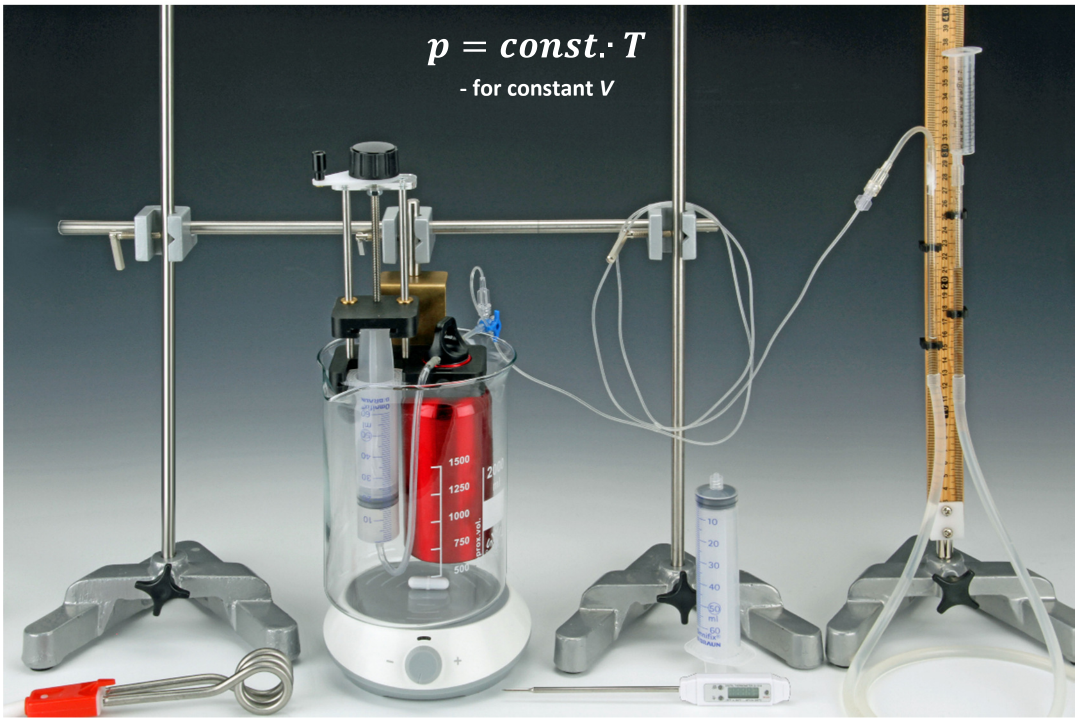
Absolute Zero (Gay-Lussac's Law)

Experiment number	132230-EN	Topic	Thermodynamics, gas laws			
Version	2019-10-02 / HS	Type	Student exercise	Suggested for grade 12+	p.	1/4



Objective

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

Principle

We investigate a fixed amount of atmospheric air with a temperature that is controlled by a water bath. The pressure is measured with a liquid manometer. To keep the volume constant, the manometer branches are moved manually to keep the liquid level in the inner branch at a fixed point in the tube.

Equipment

(Detailed equipment list on last page.)

Gas law apparatus

Beaker
Immersion heater
Thermometer
Magnetic stirrer

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).

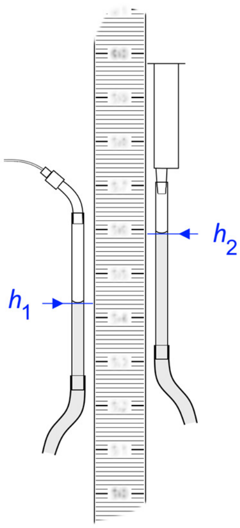
The pressure difference Δp is

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

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.

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.

When the temperature drops, the gas will contract, and it will be necessary to raise h_1 and lower h_2 in order to keep the water out of the connection hose.

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.

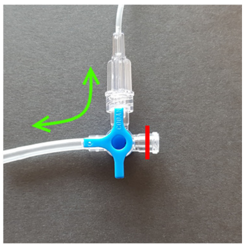
Fill the manometer with demineralized water using a squeeze bottle – avoid air bubbles in the manometer hose and the glass tubes. The ideal amount of water will make the water reach the centre of both glass tubes. (Should the water level in the outer branch be a couple of centimetres higher or lower,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

When the manometer is not connected, the pressure is the same in both branches of the manometer. Read h_1 and h_2 carefully – if they are different, this constitutes an offset error that you will need to correct in the following measurements.

Turn the spindle all the way down, making the syringe volume zero.

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



Procedure

We will start cooling the air down – keep an eye on the liquid level in the inner manometer branch!

Fill up the beaker with water as cold as possible – preferably from the fridge. 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 manometer branches to place the water in the inner tube surface precisely at the marking line. Do this for every measurement to keep the gas volume constant.

Read h_1 and h_2.

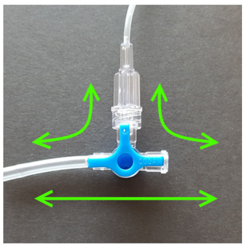
Write down the temperature.

With the immersion heater, heat the water about 10 degrees up.

Wait again a few minutes to let the temperature stabilize, adjust the manometer branches again and repeat the measurement of the liquid levels and the temperature.

Repeat with more temperatures – as long as the manometer ruler allows.

Now, move the outer branch of the manometer down to the level of the inner branch – it is OK if water flows into the overflow vessel. Turn the three-way valve to open up to the atmosphere.

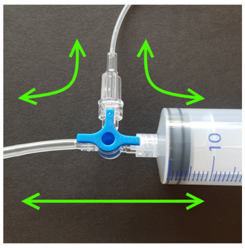


This eliminates the risk of getting water sucked into the connection hose.

If you have time enough, the measurement series can be repeated with a smaller amount of air:

Use water around room temperature and use the extra plastic syringe to lower the start pressure to have the inner manometer branch at the top of the ruler and the outer one at the bottom.

The three-way valve must connect all three sides (see image) while adjusting – after that, the syringe should be disconnected and removed.



Read the manometer and the temperature.

Continue like before with a series of measurements at higher and higher temperature.

And again: When you have completed the measurements, place the manometer branches at the same height before opening the valve to the atmosphere.

If you still have time, you can repeat the measurements yet another time, but with more air than previous:

Use again water as cold as possible, but make $h_1 = h_2$ at this temperature. (Keep the three-way valve open until you are ready to begin the measurement series.)

Like before, finish with the manometer branches back in neutral position and the valve open to the atmosphere.

One last point: Remember to find and write down the pressure of the atmosphere (the barometric pressure).

It is easiest with a barometer!

Else, try getting a value for the actual, local barometric pressure on the internet. Caution: The value may be corrected to sea level instead of the actual height where you are situated.

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.

Theory

According to Gay-Lussac's law, the pressure in an amount of gas (with a fixed volume) is proportional with the absolute temperature:

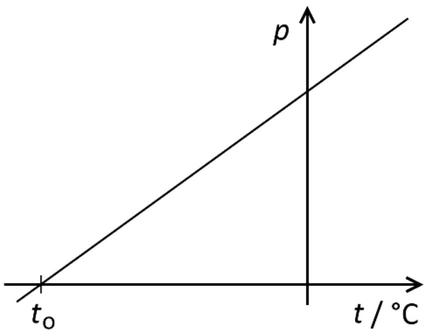
$$p = \text{const.} \cdot T$$

Absolute zero (the zero point of the kelvin scale) is the temperature where the molecules have no kinetic energy; they lie completely still and the pressure is therefore also zero.

(This is a purely mathematical extrapolation. In reality, physics at ultra-low temperatures is much more complicated.)

When measuring in degrees Celsius, the relation is no longer a proportionality, but a linear function.

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



Calculations

Convert the barometric pressure to Pa.

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

Barometric pressure			*Acceleration due to gravity*	
B =	Pa		g =	m s^{-2}
Offset correction			*Density of water*	
Δh_0 =	m		ρ_w =	kg m^{-3}

t	h_1	h_2	Δh	Δh_{CORR}	Δp	p
°C	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.

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

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

Specify your experimental value for the absolute zero.

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?

Which influence does it have on the slope of the graph that part of the gas doesn't have the temperature that you measure in the water bath? Comment on this in relation to the results.

Teacher's notes

Concepts used

Kelvin scale
Celsius scale
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
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.