

First name .....

Date .....

Last name .....

Degree program name .....

## Exercise 107

### Gas processes

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#### Table I: Part 107a - Boyle's Law

Gas temperature before compression  $t_p = \dots\dots\dots$  °C,  $T_p = \dots\dots\dots$  K

Initial syringe volume ..... ml

V, [ml]	1/V, [ml <sup>-1</sup> ]	p, [kPa]	p·V, [kPa·ml]

Gas temperature after compression  $t_k = \dots\dots\dots$  °C,  $T_k = \dots\dots\dots$  K

#### Table II: Part 107b - Isochoric process, Charles' Law

$t$	[°C]								
$p$	[kPa]								
$t$	[°C]								
$p$	[kPa]								

The ordinate intersection point ordinate       $b = \dots\dots\dots$

The slope coefficient value                       $m = \dots\dots\dots$

Designated temperature of absolute zero       $t_0 = \dots\dots\dots$  °C,  $T_0 = \dots\dots\dots$  K

Table temperature of absolute zero               $t_{tab} = \dots\dots\dots$  °C,  $T_{tab} = \dots\dots\dots$  K

## Experiment 107: GAS PROCESSES

### TARGET

Exercise **107** consists of two parts, **107a** and **107b**.

The aim of the exercise in part **107a** is to check *Boyle's law* - the relationship between pressure and volume of an air sample at constant temperature will be examined. The purpose of the exercise in part **107b** is to check the gas pressure dependence on temperature with a constant gas volume and to determine the theoretical limit of low temperature. The theoretical value of the lowest temperature is called *absolute zero*.

### TEHEORY

To describe the changes that gases undergo, the concept of an *ideal gas* has been introduced. An *ideal gas* is a gas whose molecules do not interact with each other.

The internal energy of each body is the sum of the kinetic and potential energy of the molecules it is made of. If the distances between the molecules are large, the interaction between the molecules is weak. An ideal gas is an approximation of real gas, neglecting the interaction of distance between molecules and their associated potential energy. We treat ideal gas molecules as very small, perfectly elastic spheres that experience collisions between themselves and the vessel walls. The internal energy of an ideal gas results only from the kinetic energy of molecules, which depends only on temperature. Under room conditions, real gases meet the ideal gas approximation well, and deviations from this idealization are observed at increased pressure or at low temperatures.

The state of gas as a substance can be described by giving 3 physical quantities that can be experimentally determined. These are the pressure  $p$ , the volume  $V$  and the temperature  $T$  of the gas.

#### *Ideal gas law.*

In general, when all three physical quantities characterizing the gas, i.e.  $V$ ,  $p$  and  $T$ , change with a constant mass of gas, the relationship between them can be written as follows:

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2},$$

or more generally

$$\boxed{\frac{pV}{T} = \text{constans}}.$$

In this formula, the temperature must be expressed in Kelvin.

Often the amount of gas is expressed in *moles*. A *mole* is the amount of matter equal to the mass of  $6.02 \cdot 10^{23}$  molecules of a given element or chemical compound.

The given number  $N_0 = 6,02 \cdot 10^{23}$  of molecules of a given element is called the *Avogadro number* or *Avogadro's constant* and is equal to the number of atoms contained in 12 g of the carbon  $^{12}\text{C}$  isotope. *The weight of 1 mole corresponds to the atomic or molecular weight of the substance, expressed in grams.*

The constant in the gas state equation can be easily calculated since 1 mole of gas occupies the volume  $V_m = 22,4 \text{ dm}^3$ , under pressure  $p_0 = 101,3 \text{ kPa}$  and at temperature  $T_0 = 273,15 \text{ K}$  (these are called normal conditions). We substitute these data into the equation of state for  $n$  moles of gas:

$$\frac{p \cdot V}{T} = \frac{p_0 \cdot nV_m}{T_0} = n \frac{p_0 \cdot V_m}{T_0} = nR, \quad \text{where} \quad R = \frac{p_0 \cdot V_m}{T_0}.$$

After substituting the numerical data, we get  $R = 8,31 \text{ J}/(\text{mol} \cdot \text{K})$ .

$R$  is an important physical constant and it is called the *gas constant*. The equation of state of an ideal gas for  $n$  moles can therefore be written as:

$$pV = nRT .$$

The gas state equation written in this way is called the *Clapeyron equation*. If we denote the mass of gas by  $m$ , and by  $\mu$  - the molecular weight, then  $n = m/\mu$ .

The general equation of gas state gives rise to special relationships between two of the three quantities, when one of them is constant. These relationships are known as the laws of gas changes.

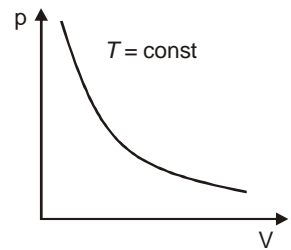
### Isothermal process

In isothermal process, the gas temperature is constant. Then the product of the pressure of a given mass of gas and its volume is a constant value:

$$T = \text{const} , \quad pV = \text{const}$$

This relationship is called the *Boyle and Mariotte law*. The diagram of the isothermal process is called the *isotherm*.

The *Boyle and Mariotte law* shows that for an ideal gas at constant temperature, pressure is inversely proportional to volume.

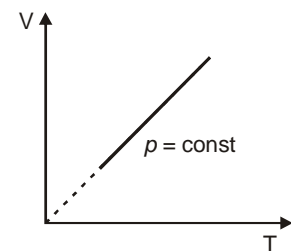


### Isobaric process

In the isobaric process, pressure is a constant value, in addition to the mass of gas. In this process, the quotient of gas volume and temperature is a constant value:

$$\text{for } p = \text{const} , \quad \frac{V}{T} = \text{const} .$$

The equations for the isobaric process show a linear relationship between the volume and temperature of the gas. This relationship is known as the *Gay-Lussac law*.



Let's try to express the formula for the isobaric process when the temperature is on the Celsius scale:

$$\frac{V}{T} = \frac{V_0}{T_0} = \frac{V_0}{273,15} \Rightarrow V = V_0 \frac{T}{273,15} = V_0 \frac{t + 273,15}{273,15} = V_0 \left(1 + \frac{1}{273,15} t\right) .$$

If we mark it as a:  $\beta = \frac{1}{273,15} \frac{1}{^\circ\text{C}}$ , we get the known formula for volumetric expansion:

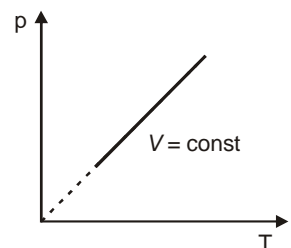
$$V = V_0(1 + \beta t) .$$

In this formula, it means the volume of gas at  $0^\circ\text{C}$ , and  $\beta$  the value of the volumetric expansion coefficient which is the same value for each gas.

### Isochoric process

The third transformation of an ideal gas is the isochoric process. At a constant mass of gas and a constant volume, the quotient of pressure and temperature is a constant value:

$$\text{for } V = \text{const} , \quad \frac{p}{T} = \text{const} .$$

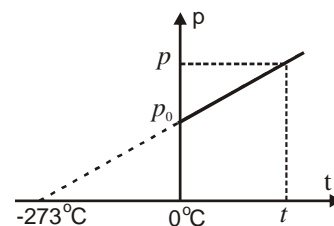


This relationship is called *Charles's law*. When we express the temperature in degrees Celsius, we get:

$$p = p_0(1 + \gamma t) .$$

Here it means the gas pressure at 0°C, and  $\gamma$  is the *coefficient of resilience*, which has the same value for any gas, the same as  $\beta$ .

The figure opposite shows how, on the basis of a simple measurement of the temperature dependence of gas pressure, you can check the value of the absolute zero temperature in degrees Celsius - to do this, you should extend the pressure graph until it crosses the temperature axis.



## PERFORMING THE EXPERIMENT

### Part 107a. Testing Boyle's law

EQUIPMENT	
<ul style="list-style-type: none"> <li>PC with „SPARKvue”</li> </ul>	<ul style="list-style-type: none"> <li>Temperature sensor - PASCO wireless <b>temp link</b></li> </ul>
<ul style="list-style-type: none"> <li>Pressure sensor - PASCO wireless <b>pressure</b></li> </ul>	<ul style="list-style-type: none"> <li>Syringe-temperature sensor system</li> </ul>

In this part of the experiment we will check whether, according to Boyle's law, for a constant mass of gas at a constant temperature, pressure is inversely proportional to volume.

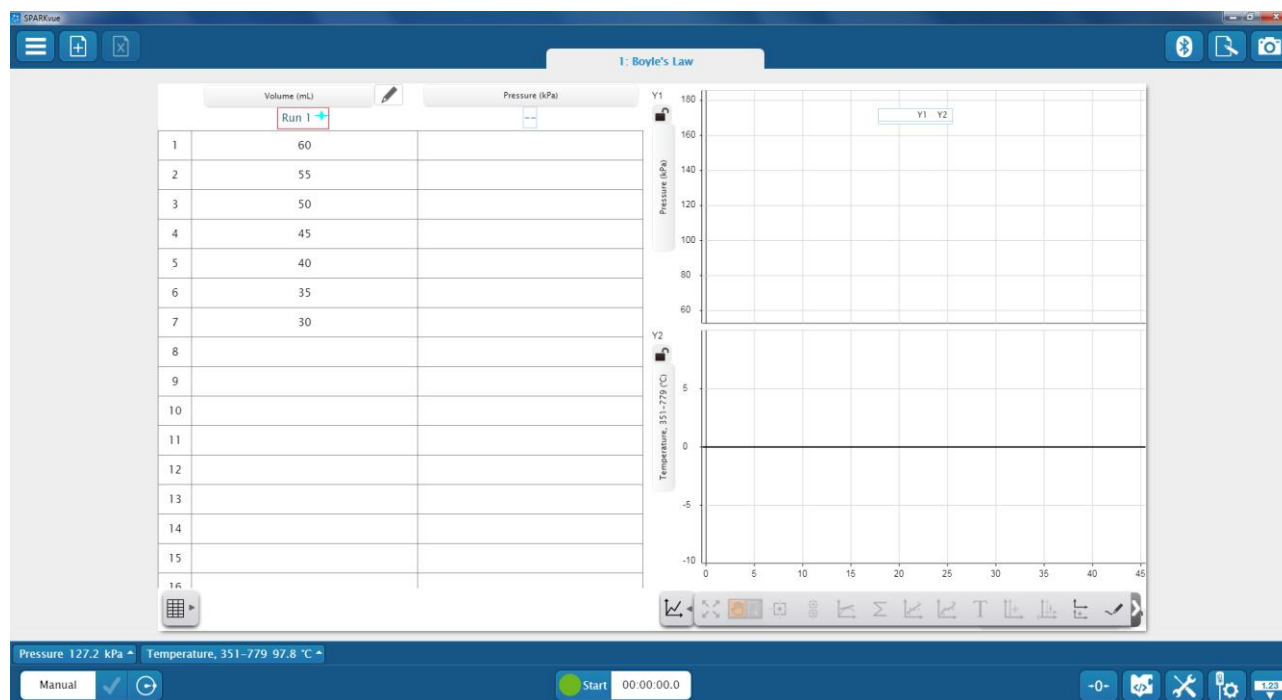
Prepare the computer - do not save files changes (DON'T SAVE)

1. Turn on the power to the table (see the table dashboard - by your left leg when you are sitting in front of the computer) - turn the red "knob" in the direction of the arrows (it should pop out), turn the key like in a car and release it. Turn on the computer.
2. The *Windows* operating system will start automatically. Log in by pressing user icon **107**. Turn on the power of the PASCO wireless **pressure**, and PASCO wireless **temp link** sensors. Sensors turn off when not in use. In the middle of the desktop there is a shortcut 107a - it launches the "SPARKvue" program along with the file supporting the exercise – run it! Expand the window to full screen.
3. Tap the Bluetooth icon (upper right corner of the window). Connect the temperature sensor (351-779 Temperature) and pressure sensor (135-338 Pressure) by clicking it in the devices window. Once added correctly, click "Done". The correct connection of the sensors is shown in the photo below. **Do not connect other sensors!**



## Experiment window 107a

Basic window "Boyle' Law" - contains control buttons, a table, a pressure versus volume graph and a graph of air temperature changes in the syringe system. The numerical values will change automatically during measurements.




### Preparation of the measuring system

1. Before connecting, set the syringe plunger to 60 ml.
2. Connect the plug at the end of the **green** plastic cable coming from the PASCO wireless **pressure** sensor to the syringe system.
3. Connect the temperature sensor - **silver** mini stereo jack cable to the temperature sensor - PASCO wireless **temp link**.

**ATTENTION! Check that the silver mini stereo jack is fully pushed in. Incorrect connection causes erroneous temperature readings.**

### Recording of measurements

1. Press the "Start" button (when data collection is active, a red square is displayed and the time is counted down).
2. With a volume of 60 ml, confirm the first measurement by clicking the green check mark next to "Manual" 
3. Change the syringe volume every 5 ml and confirm the measurement each time.
4. To end the measurements, press "Stop".
5. Disconnect the green plastic tubing from the syringe and the mini stereo jack cable from the temperature sensor.

### Data analysis

1. Use the "Scale to fit" button to fit the charts to the windows.
2. Read the gas temperature before and after compressing the air. Record the value of the initial  $t_p$  and final  $t_k$  temperatures in the table. Read these values from the temperature-volume graph by clicking on the appropriate point - the "Add coordinates tool" option will appear.
3. Fill in the table with the relevant data from the table obtained during the experiment.
4. Perform a pressure  $\times$  volume calculation for each volume value. Describe the conclusions from the obtained figures and graphs.

### Part 107b - Isochoric gas process, Charles' Law

EQUIPMENT	
<ul style="list-style-type: none"> <li>• PC with „SPARKvue”</li> </ul>	<ul style="list-style-type: none"> <li>• Temperature sensor - PASCO wireless <b>temp link</b></li> </ul>
<ul style="list-style-type: none"> <li>• Pressure sensor - PASCO wireless <b>pressure</b></li> </ul>	<ul style="list-style-type: none"> <li>• Metal sphere with heating system</li> </ul>

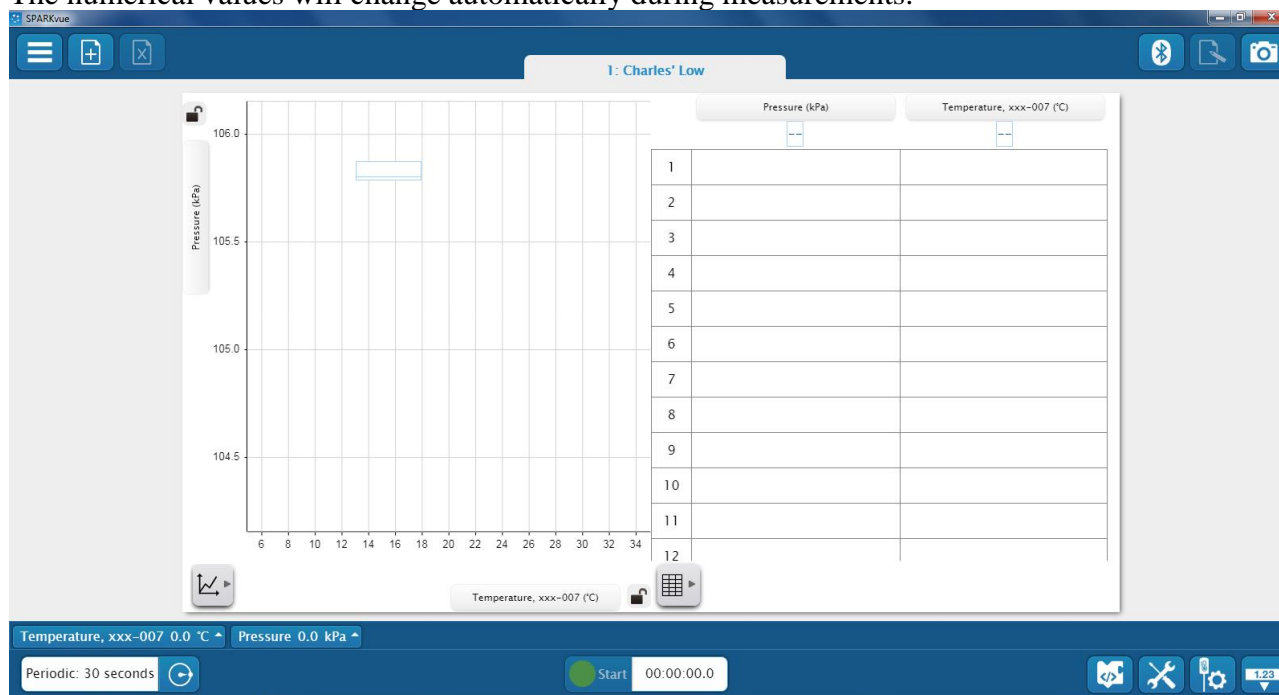
In this part of the experiment, the isochoric process will be investigated - the gas closed in a rigid container (metal sphere) with a constant volume will be heated from room temperature to a temperature of about 70°C. The obtained diagram of the process should be a straight line, which makes it possible to check the theoretical limit of low temperatures

Prepare the computer - do not save changes to files (DON'T SAVE)

1. Close the previous window.
2. Turn on the power of the PASCO wireless pressure, and PASCO wireless temp link sensors *if they are “standby” or turn off*. Sensors turn off when not in use. In the middle of the desktop there is a shortcut 107b - it launches the "SPARKvue" program along with the file supporting the exercise - run! Expand the window to full screen.
3. Tap the Bluetooth icon (upper right corner of the window). Connect the temperature sensor (351-779 Temperature) and pressure sensor (135-338 Pressure) by clicking it in the devices window. Once added correctly, click "Done". The correct connection of the sensors is shown in the photo from the earlier part of the exercise. Do not connect other sensors!

## Experiment window 107b

Basic window "**Charles' Law**" - contains control buttons, table, pressure vs. temperature graph. The numerical values will change automatically during measurements.



### Preparation of the measuring system

The experimental system is a metal spherical air tank in the shape of a sphere, in the outlets of which pressure and temperature sensors are placed. Everything is permanently placed in an electric heater. **It is not allowed to disassemble or change the connections of the system!**

1. Connect the plug on the end of the **transparent** plastic wire coming from the metal sphere to the **green** plastic wire coming from the PASCO wireless pressure sensor.
2. Connect the **black** mini stereo jack cable coming from the metal sphere to the temperature sensor - PASCO wireless **temp link**.


**Check that the black mini stereo jack is fully pushed in. Incorrect connection causes erroneous temperature readings.**

### The course and recording of measurements

1. Turn on the sphere heating - **switch on the electric splitter**. Wait 3 minutes for measurement conditions to stabilize.
2. Press the "Start" button (when data collection is active, a red square is displayed and the time is counted down). Measurements will be collected every 30 seconds.
3. Continue the measurement until the gas in the sphere reaches a temperature of approx. 80°C. See the window **Temperature!**
4. Press "Stop", to complete the data registration.
5. Turn off the sphere heating - **switch off the electric splitter**.

**VERY IMPORTANT! Inform the tutor that part C09 of the exercise has been completed. The tutor checks if the heating system has been turned off.**

## Data analysis

1. Now we are working in the chart window. In the function bar, the "paw"  should be highlighted in orange.
2. Hover over the temperature axis. By holding down the left mouse button and moving it left or right, adjust the range of this axis from approximately "-300" as a minimum to "+100" as a maximum.
3. After hovering the cursor over the graph field, you can change the position of the experimental points by moving left or right.
4. Similarly, adjust the pressure axis so that its range is from approximately "-30" as a minimum to "+130" as a maximum.
5. Similarly to before, after moving the cursor over the graph field, you can change the position of the experimental points by moving it up or down.
6. Fit a straight line to the measurement points using the "Show/hide linear fit" function button.
7. The coordinate of the point of intersection of the temperature axis with the extension of the straight line fit is the approximate experimental value of the *absolute zero temperature*  $t_0$ , corresponding to the zero value of the ideal gas pressure. The coordinate of the pressure axis in this case is zero ( $y = 0$ ).
8. Based on the data contained in the statistics field for the fitted line, calculate the coordinate of the intersection of the temperature axis ( $x$ ) by transforming the equation  $y = mx + b$ . The value of the  $b$  ordinate and the slope of this line - read the  $m$  coefficient from the statistics field. If we denote as  $t_0$  the coordinate the point  $x$  for which  $y = 0$ , then  $t_0 = -\frac{b}{m}$ . The calculated value is equal to the  $t_0$  value read directly from the graph.
9. Complete the exercise table with data from the table window.