„C H A R L E S"

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Theoretical Introduction

Experiment "C H A R L E S"

One mole is the amount of substance, for example atoms, molecules, ions or electrons, which contains: $6{,}02214076 \cdot 10^{23}$ particles. A mole is a number, so it is dimensionless. However, this number is also known as Avogadro's constant $\boldsymbol{N_A}$, which relates the number of moles to the number of particles of a substance $\boldsymbol{N}$:

$$n = \frac{N}{N_A},$$

where: n – number of moles, N – number of particles of the substance, N_A – Avogadro's constant describing the number of particles in one mole of a substance; it has the unit 1/mol, ($N_A = 6{,}02214076 \cdot 10^{23}\ mol^{-1}$).
One mole of a given substance has a mass equal to its molecular mass expressed in grams. For example: 1 mole of helium has a mass of 4 g, 1 mole of atomic hydrogen - 1 g, 1 mole of molecular hydrogen- 2 g, 1 mole of water - 18 g.

The molar concentration of a gas $c_m = \frac{n}{V}$ is the number of gas particles expressed in moles per unit volume.

At a temperature of 0°C and a pressure of 1 atm the volume of 1 m^3 of air contains 44,6 moles of air molecules, (nitrogen N_2, oxygen O_2, carbon dioxide CO_2 and others), so the molar concentration of air is: 44,6 mol/m^3. At a temperature of 25°C the concentration is lower and equals : 40,9 mol/m^3.

Pressure is the force acting on a certain surface area: $p = \frac{F}{s}$
The basic SI unit of pressure is the pascal: (1Pa = 1N/m^2). It is a unit defined using the basic SI units. In practical technical applications, non-SI units are often used: millimetre of mercury, mmHg, atmosphere, atm, bar, psi, and metre of water column..

The Clapeyron equation describes an ideal gas. It also describes rarefied real gases with good approximation. It is the relationship between pressure p, volume V, and temperature T, expressed on the absolute Kelvin scale, which occurs in a sealed system, that is, for a constant amount of gas particles expressed in moles:

$$p\,V = n\,R\,T$$

where: $R = 8{,}314 \left[\frac{J}{mol \cdot K}\right]$ is the gas constant.
The Clapeyron equation was formulated on the basis of previously discovered laws: Boyle-Mariotte's law, Charles's law and Gay-Lussac's law.

Isothermal Process - Boyle's Law:
If: $T = const$ and the container is sealed: ($n = const$), then, from the Clapeyron equation, it follows that: $p{\cdot}V = const$
In an isothermal process, the relationship between pressure and volume is: $p(V) = nRT\,V^{-1}$

Isobaric Process – Gay-Lussac's Law:
If: $p = const$, then, from the Clapeyron equation, it follows that: $V/T = const$
In an isobaric process, the relationship between volume and temperature is: $V(T) = nR / pT$

Isochoric Process – Charles's Law:
If the container is sealed and its volume is constant: $V = const$, then, from the Clapeyron equation, it follows that:

$$p/T = const.$$

Therefore, pressure is proportional to temperature: ($p = const \cdot T$) When the temperature of the gas in the container increases, the pressure also increases, and when the temperature of the gas decreases, the pressure also decreases.

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Preparation Questions:

1. Write the Clapeyron equation as a formula.
2. Write the equation of state of an ideal gas.
3. Write the basic formula of the kinetic theory of gases, average kinetic energy of gas molecules.
4. Give the definition of pressure and its basic SI unit.
5. Characterize at least three non-SI units of pressure.
6. Explain what temperature is and give its SI unit.
7. Explain what absolute zero temperature is.
8. By how many kelvins will the temperature increase if the increase is $1^{\circ}C$?
9. Explain what a thermodynamic process is.
10. Characterize an isothermal process and give the equation of state describing it.
11. Characterize an isobaric process and give the equation of state describing it.
12. Characterize an isochoric process and give the equation of state describing it.
13. Characterize an adiabatic process and give the equation of state describing it.
14. Present an isobar on a $V(T)$graph and an isochore on a $p(T)$graph.
15. Give the values of pressure, temperature and volume parameters for one mole of gas under normal conditions.

Instructions for Performing the Measurements

1. Place the glass flask with air in a water bath. If necessary, refill the water level using distilled water only.
2. Turn on the thermostat and set the water temperature to about $70^{\circ}C$.
3. Turn on the thermometer placed in the flask and the differential barometer. Observe the temperature increase and the accompanying pressure increase inside the flask.
4. When the temperature of the air in the flask reaches about $50^{\circ}C$, remove the vessel from the water bath, dry it with a paper towel and prepare to record the measurements.
5. Wait until the temperature drops by $2^{\circ}C$.
6. During the cooling of the flask, perform 10 measurements of the pressure of the air inside the vessel and its temperature. Take readings approximately every $1^{\circ}C$.
7. If the thermometer or manometer switches off, turn the instrument on again and continue the measurements.
8. Perform the calculations according to the instruction and prepare a trial graph in a spreadsheet. In the calculations, remember to use the basic SI units for temperature and pressure.
9. Prepare a measurement protocol and measurement uncertainties.

NOTE:

The system may be unsealed only when the temperature of the flask is the same as the ambient temperature.
Note that the same internal pressures during heating and cooling correspond to different temperature readings. This is caused by the slow reaction of the thermometer to changes in gas temperature. The measurements are performed during cooling, which occurs more slowly than heating. Then the measurements are burdened with a smaller systematic error.

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Methodological Template

Student 1: Determination of the molar concentration of air.
Student 2: Verification of Charles's law.

Theoretical Basis

The Clapeyron equation of state of an ideal gas:

$$p \cdot V = nRT$$

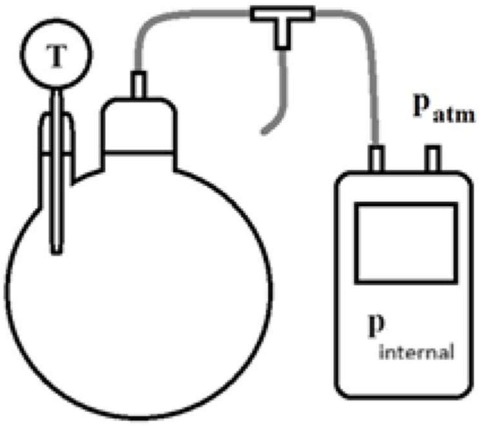
where: p – gas pressure, V – gas volume, n – number of moles of gas, $R = 8{,}314 \left[\frac{J}{mol \cdot K}\right]$gas constant, T – temperature in kelvins.

In the flask, gas pressure can be expressed as the sum of internal and external, atmospheric, pressure:

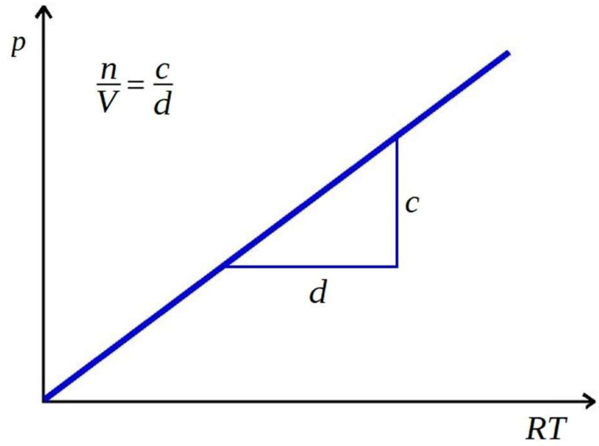
$$p = p_{atm} + p_{wewn}$$

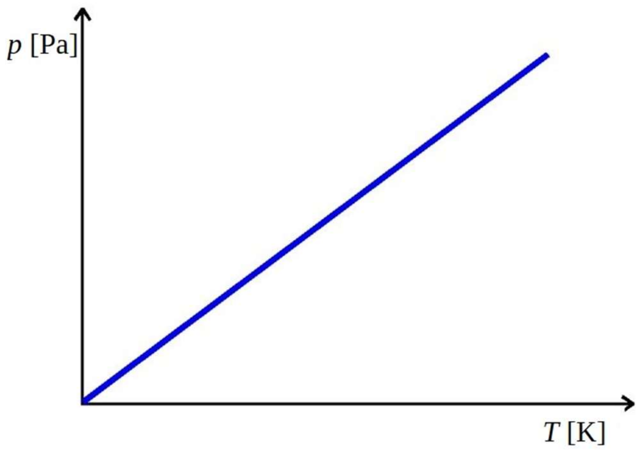
Charles's law: in a sealed vessel with constant volume V, the gas pressure $p$is proportional to its temperature T:

$$p = const \cdot T$$



$$\underbrace{p_{internal}}_{Y} + p_{atm} = \underbrace{\frac{n}{V}}_{a} \cdot \underbrace{RT}_{X}$$





Therefore, in order to determine the molar concentration of air, one should:

- perform measurements of the dependence of the pressure of the air inside the vessel on its temperature,
- prepare a graph of the dependence:

  p = f(R·T)
- read the molar concentration of air as the slope coefficient of this graph.

Therefore, in order to verify Charles's law, one should:

- perform measurements of the dependence of pressure on temperature,
- prepare a graph of the dependence:

  p = f(T)
- analyse its linearity

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Report Guidelines – Determination

Student 1: Determination of the molar concentration of air.

I. Methodology (conceptual plan of the exercise)

II. Course of exercise

II.1. Course of activities

II.2. Sketch of the measurement setup

III. Results

III.1. Measurement results

		1	2	3	4	5	6	7	8	9	10
p_{wewn}	[Pa]										
t	[°C]										

p_{atm} = ... [hPa] = ... [Pa]

$\Delta p_{internal}$ = Δp_{atm} = Δt =

III.2. Calculations (example calculations - referring, for example, to measurement no. 3)

$p = p_{internal} + p_{atm} =$

$R{\cdot}T =$

$\Delta(p) = \Delta p_{internal} + \Delta p_{atm} =$

$\Delta(RT) = R \cdot \Delta T =$

III.3. Calculation results

		1	2	3	4	5	6	7	8	9	10
p	[…]										
$R{\cdot}T$	[…]										

III.4. Graph

- calculation of: n/V (the slope of the “best-fit” straight line)
- calculation of: (n/V)’ (the slope of the deviated straight line)
- calculation of: Δ(n/V) = |n/V – n/V’|

IV. Summary

The determined molar concentration of air is …
The accuracy of the method is: …
Additional conclusions, observations, causes of measurement uncertainties.

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Report Guidelines - Verification

Student 2: Verification of Charles's law.

I. Methodology (conceptual plan of the exercise)

II. Course of the exercise

II.1. P Course of activities

II.2. Sketch of the measurement setup

III. Results

III.1. Measurement results

		1	2	3	4	5	6	7	8	9	10
$p_{internal}$	[Pa]										
t	[°C]										

$p_{atm} =$ . . . . [hPa] = ... [Pa]

$\Delta p_{\mathrm{internal}} =$ $\Delta p_{\mathrm{atm}} =$ $\Delta t =$

III.2. Calculations (example calculations - referring, for example, to measurement no. 3)

$p = p_{internal} + p_{atm} =$

$T =$

$\Delta(p) = \Delta p_{internal} + \Delta p_{atm} =$

$\Delta(T) =$

III.3. Calculation results

		1	2	3	4	5	6	7	8	9	10
p	[...]										
T	[...]										

III.4. Graph

IV. Summary

Since on the graph … it is possible to draw a straight line passing through all measurement uncertainty rectangles, there are no grounds to conclude a deviation from …
Alternatively:
The deviation from linearity in the range … may result from …
Additional conclusions, observations, causes of measurement uncertainties.