CHARLES 'LAW

1. PURPOSE OF THE WORK

Observation of volume variation with temperature at constant pressure for a quantity of gas (air).

2. THEORETICAL NOTIONS

The state of a gas is determined by temperature, pressure and the amount of substance. In the particular case of the ideal gas, these variables are related by the equation of state of the ideal gas. The connection between these quantities is highlighted by writing the next total differential:

$$dV = \left(\frac{\partial V}{\partial T}\right)_{P,n} dT + \left(\frac{\partial V}{\partial P}\right)_{T,n} dP + \left(\frac{\partial V}{\partial n}\right)_{T,P} dn \qquad (1)$$

The equation of state of the ideal gas turns into Charles's law, when working under isobaric conditions (*p* = ct). For a known amount of the substance (*n* = const; *dn* = 0; the amount of air in the syringe) and for isobaric conditions (*p* = const; *dp* = 0), the relation (1) becomes:

$$dV = \left(\frac{\partial V}{\partial T}\right)_{P,n} dT \qquad (2)$$

The partial derivative $\left(\frac{\partial V}{\partial T}\right)_{P,n}$ corresponds from the geometric point of view to the slope of the tangent to the function V = f(T) and thus characterizes the volume dependence of the temperature. The degree of this dependence is determined by the initial volume. The coefficient of thermal expansion is defined as a measure of volume temperature dependence (where $V = V_0$ for T_0 = 273,15 K):

$$\alpha_0 = \frac{1}{V_0}\left(\frac{\partial V}{\partial T}\right)_{P,n} \qquad (3)$$

For the limit case of the ideal gas, the integration of differential equations (2) and (3), in which $\alpha_0 = \text{const.}$, leads to

$$\frac{V_0}{T_0} = \frac{V}{T} \qquad (4)$$

and

$$V = const \cdot T \qquad (5)$$

Based on this relation, the graphical representation of the volume as a function of temperature is a line where $V = V_0$ for $T = T_0$.

From equation (3) and from the law of the ideal gas

$$PV = nRT \tag{6}$$

(where R is the universal gas constant) is obtained

$$\left(\frac{\partial V}{\partial T}\right) = V_0 \cdot \alpha_0 = \frac{n \cdot R}{P} \tag{7}$$

From this relation, we can also determine experimentally α and R if we know the initial volume V_0 and the amount of substance, n (P is the atmospheric pressure).

3. EXPERIMENTAL PART

3.1. APPARATUS AND SUBSTANCES

-Cobra 3 basic-unit
-12 V / 2 A power adapter
-RS232 data cable
-Module for measuring temperature
-NiCr-Ni thermocouple
-100 mL glass syringe with glass jacket
-Heating hob
-Power regulator
-Computer, software Cobra 3 “The laws of the ideal gas”

Fig. 1. Experimental installation

3.2. PROCEDURE

Fill the glass jacket with water with the funnel and insert a magnetic bar. Fix the initial volume of the syringe at 50 mL, by carefully removing the rubber stopper (black), without breaking or bending the thermocouple (the wire passing through the rubber stopper), then replace this stopper, as tight as possible. Check the position of the thermocouple so that it is centrally located in the syringe, without touching its walls or the plunger. Open the software called "Measure" in Windows and use the "Ideal gas law" module. The measurement parameters are set as follows:

-Channels menu:

-pick p, at the Source option choose “const.”;

- T is checked, at the Source option “modules” are chosen, “NiCr-Ni” is chosen at the sensor;

- check *V*, for the Source option select “manual”, set 50 mL for the “Start volume” option, set 1 mL for the “volume increment” option, and choose option increase at the “Change of volume”;
- at the option “Calculate automatically” tick *pV*/*T*, and at “X data” tick “Number”;
- “Start / Stop” menu: choose “Get value on key press”;
- “Other Settings” menu: select digital display 1 for temperature T_1 and diagram 1 with channel temperature *T*, *x* bounds “from 1 to 15” and “No auto range” mode.

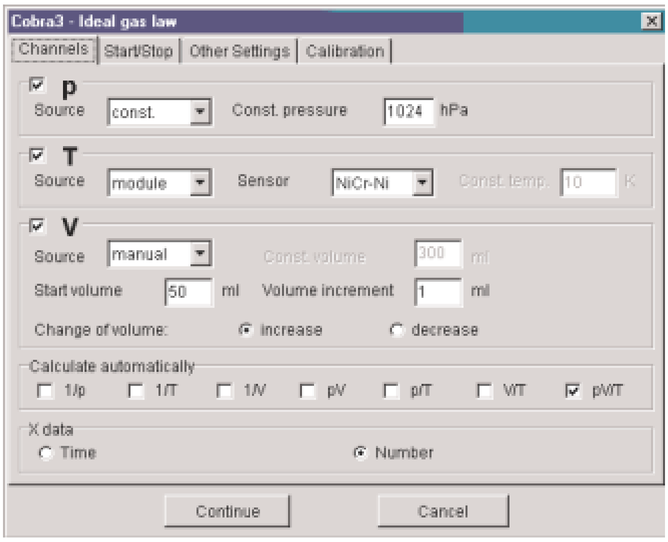

Fig. 2. Software interface ("Channels" menu”)

If necessary, then calibrate the sensor in the Calibration menu by entering the temperature value measured with a thermometer and press "calibrate". Then press "continue" to enter the measurement recording menu. The measured values are noted in a table:

***V*, mL**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
***T*, K**											

The first temperature value is also recorded on the computer by pressing “save value”, then the heating is started and the power regulator is set to stage 5 or 6. Carefully shake the water with the magnetic wand without touching the syringe. After the volume changes by 1 mL, press “save value” again and note the new temperature in the table.

When the volume of 60 mL has been reached or the temperature exceeds 363 K, the heating is stopped and the recordings are stopped by pressing “close”. Save the measurements by selecting the file / save measurement menu as "Date_group_name".

To save the values in an accessible format, they are exported by checking "As numbers" and "To file" and saving as a tab named "Date_group_name.txt".

To obtain the graph *V* = f(*T*), in the measurement menu, choose Channel manager, choose "Temperature" for the x-axis and "Volume" for the y-axis.

4. EXPERIMENTAL DATA PROCESSING

4.1. The variation of the volume with the temperature is represented graphically;

4.2. Determine the slope (*m*) of this graph;

4.3. The amount of substance (*n*) is calculated by reporting the initial volume of gas, V_0, recalculated for the temperature of 273.15 K, using the graph obtained from the experiment $V = f(T)$, to the molar volume of one mole of gas under normal conditions (V_m = 22.414 L · mol-1, T_0 = 273.15 K; p_0 = 1013.25 hPa (mbar))

$$V_{273} = V_0 + \Delta V \quad , \quad \Delta V = m \cdot (273 - T_0) \quad , \quad n_{aer} = \frac{V_{273}}{V_m}$$

4.4. From the slope of the graph, *m* and from the number of moles of air are calculated on the basis of the relation (7) the universal constant of the gases *R* and the coefficient of thermal expansion, α. The values obtained are compared with the theoretical ones (R = 8,31441 $J \cdot K^{-1} \cdot mol^{-1}$, $\alpha = 3{,}661 \cdot 10^{-3}$ K^{-1}).

Remarks

1. It is not necessary to make the settings for each new experiment. It is necessary to enter the initial temperature.
2. It is important that the initial temperature is that of the water in the glass mantle.

5. QUESTIONS

5.1. How does the volume of gas change with temperature? What do you notice if you plot $V = f(t / °C)$ and $V = f(T / K)$?

5.2. Which product or property ratio remains constant ($P \cdot T$, $T \cdot V$, P/V, V/T, etc.)? What is the value of this constant?

5.3. Derive the relationship between two volumes of gas, V_1 and V_2, at temperatures T_1 and T_2, respectively.

5.4. If a gas sample at constant pressure has a volume of 417 mL at 32.4 °C, what will be its volume if the temperature rises to 64,8 °C?