Laboratory work № 2.26

Determination of the ratio of specific heat of gases by the method of adiabatic expansion

Devices and materials: the closed glass cylinder with the crane valve, the manometer, the piston manual pump.

Purpose: acquaintance with gas processes, measurement of the ratio of specific heat of gases by the method of adiabatic expansion.

Theoretical introduction

The heat capacity C of a body is a physical quantity equal to the amount of heat that must be transferred to the body to change its temperature by one kelvin (degrees), or,

$$C = \frac{\delta Q}{dT} \tag{1}$$

Heat capacity depends on the amount of substance in the body. The specific heat capacity c is the heat capacity per 1 kg of substance:

$$c = \frac{1}{m} \cdot \frac{\delta Q}{dT} = \frac{C}{m}, \tag{2}$$

and the molar heat capacity C_{mol} - respectively, per 1 mol of substance:

$$C_{mol} = \frac{C}{\nu}, \tag{3}$$

where $\nu = m / M$ is the number of moles of the substance in a body, m is a mass of substance in the body, M is a molar mass of the substance.. The heat capacity depends on the conditions under which the heating takes place. You can heat at a constant volume or at a constant pressure. The designation of heat capacity is accompanied by the corresponding indices: C_V, C_p. In this case, Cp is always greater than C_V. This is due to the fact that to heat a gas with a constant volume, the entire amount of heat goes only to increase the internal energy of the gas. When heating the gas at constant pressure, in addition to the heat that goes to increase the internal energy of the gas, you also need heat to work on the expansion of the gas (to maintain a constant pressure). The ratio of molar heat capacities $C_з/C_м$ or, as it follows from the definition, equal to the ratio of specific heat capacities is called the adiabatic exponent (Poisson's ratio) and is included in the equations linking gas parameters in the adiabatic process 4

$$pV^{\gamma} = \text{const} \; ; \; TV^{\gamma-1} = \text{const}, \tag{4}$$

or,

$$T^{\gamma} p^{\gamma-1} = \text{const.} \tag{5}$$

An adiabatic process is a change in the state of a gas that occurs without heat exchange with the environment. Then the first law of thermodynamics

$$\delta Q = dU + \delta A \tag{6}$$

for the adiabatic process will take the form dU + dA = 0, or dA = - dU. Therefore, the expansion work will take place by reducing the internal energy of the gas, and the temperature will decrease. In the case of adiabatic compression, when the work is carried out by external forces and the work of the gas is negative, the gas temperature will rise. In practice, adiabaticity is achieved by a sufficient rate of change of gas state. The speed of the process should be high enough to be able to neglect the heat exchange with the environment

Method theory and alliance description.

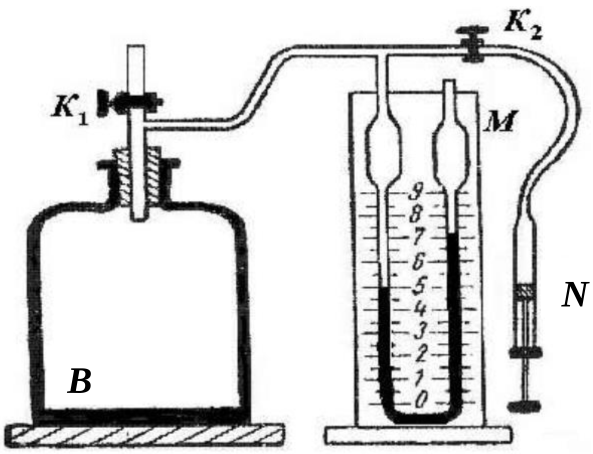


Figure 1

The main part of the alliance (Fig. 1) is a large glass cylinder B, filled with air and connected by rubber tubes with a manometer M, and through the valve K_2 - with the pump N. The valve K_1 connects the cylinder with the surrounding air. Suppose that +the cylinder first had an atmospheric pressure of p_0. Using a pump, pump a small amount of air into the cylinder and close the valve K_2. The pressure in the cylinder will increase. Excess pressure over atmospheric pressure can be determined by a manometer. Denote by p_1 the pressure of compressed air inside the cylinder, which corresponds to the readings of the manometer h_1 (the difference in levels in both knees of the manometer). It is clear that $p_1 = p_0 + \rho g h_1$. Here $\rho g h_1$ is the column pressure h_1 of the manometric fluid, ρ is the density of this fluid, g is the acceleration of free fall. When the gas in the cylinder, which was heated during compression, cools and assumes room temperature, you can start the experiment.

The nature of the processes in the experiment is convenient to trace using pV - diagram (Fig. 2).

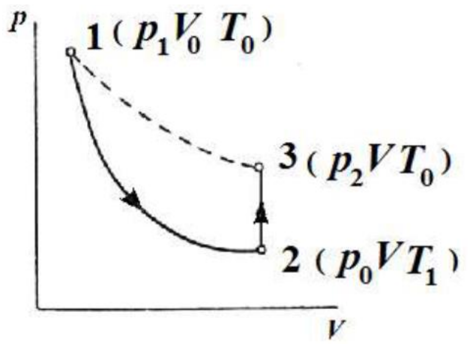
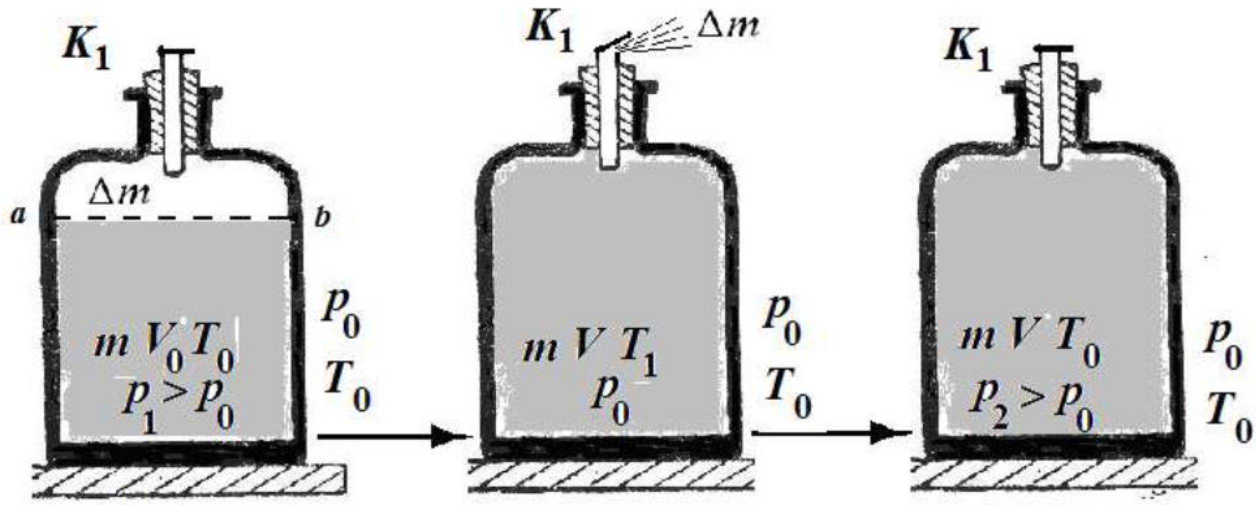


Figure 2

Select a volume of gas V_0 in the cylinder, which reaches, for example, the level of the dotted line ab (Fig. 3).



The beginning of the experiment *Adiabatic expansion* *Isochoric heating*

Figure 3

We will consider this volume of gas in the future. Let the mass of air in the volume V will be m. The state of this gas mass m, which corresponds to the beginning of the experiment, is represented on the pV diagram by point 1 with the parameters p_1, V_0, T_0 (Fig. 2). Fig. 3. In Fig.3 T_o - ambient temperature, compressed air pressure is more than atmospheric, $p_1 > p_0$. If you now quickly open the valve K_1 for a short time (0.3 - 0.5 s), the air in the volume V_0, expanding when the valve is opened, will now occupy the entire volume of the cylinder V. The mass Δm of air leaves the cylinder. The air in the vessel will expand until its pressure becomes equal to atmospheric p_0. The expansion of the air is very fast, and in this short period of time the heat exchange between the gas and the walls of the cylinder does not occur. For this reason, the process of air expansion can be considered adiabatic. The air is cooled to a temperature of T_1 and goes into a new state. This will be the second state of the gas (on the graph point 2 with the parameters p_0, V, T_1). Then cooled during the expansion of the air in the vessel as a result of heat exchange will be heated, and the pressure inside the vessel will begin to rise slowly. The pressure rise will stop when the temperature of the air in the vessel equals the room temperature T_0. This will be the third state of the gas (point 3 in the graph with parameters p_2, V, T_0). Fig.2 4 Denote the air pressure in the vessel at this time by p_2 and the corresponding reading of the manometer by h_2. It is clear that $p_2 = p_0 + \rho g h_2$ Since the transition from state 1 to state 2 occurred adiabatically, we apply the adiabatic equation that connects pressure and temperature: $T^{\gamma} p^{\gamma-1}$.= const. , $T_0^{\frac{\gamma}{\gamma-1}} p_1 = T_1^{\frac{\gamma}{\gamma-1}} p_0$, $\frac{p_1}{p_0} = \left(\frac{T_1}{T_0}\right)^{\frac{\gamma}{\gamma-1}}$. Substituting of the parameters values corresponding to the beginning and end of the adiabatic extension gives

$$T_0^{\frac{\gamma}{\gamma-1}} p_1 = T_1^{\frac{\gamma}{\gamma-1}} p_0, \text{ or, } \frac{p_1}{p_0} = \left(\frac{T_1}{T_0}\right)^{\frac{\gamma}{\gamma-1}}. \tag{1}$$

Transition from state 2 to state 3 is an isochoric process. The equality $\frac{p}{T} = const$ holds for it. In our notation

$$\frac{p_0}{T_1}=\frac{p_2}{T_0}\text{,or,}\quad \frac{p_0}{p_{21}}=\frac{T_1}{T_0}\,.. \qquad (2)$$

Substitution (2) in (1) gives:

$$\frac{p_1}{p_0}=\left(\frac{p_0}{p_2}\right)^{\frac{\gamma}{\gamma-1}} \qquad (3)$$

By taking a logarithm of the right and left parts of the equality (3), we obtain

$$\ln\frac{p_1}{p_0}=\frac{\gamma}{\gamma-1}\ln\left(\frac{p_0}{p_2}\right) \qquad (4)$$

Wewill consider separately the expressions $\frac{p_1}{p_0}=\frac{p_0+\rho g h_1}{p_0}=1+\frac{\rho g h_1}{p_0}$, and

$\frac{p_0}{p_2}=\frac{1}{1+\frac{\rho g h_2}{p_0}}{}_2$. In the second fraction we used the formula of approximate

calculations, namely for small $x<<1$ there is an approximate equality

$$\frac{1}{1+x}\approx 1-x\,.$$

Indeed, in our case the value of x is small compared to unity:

$$x=\frac{\rho g h}{p_0}\approx\frac{10^3\cdot 10\cdot 10^{-1}}{10^5}\approx 10^{-2}\,.$$

Then we will rewrite equation (4):

$$\ln\left(1+\frac{\rho g h_1}{p_0}\right)=\frac{\gamma}{1-\gamma}\cdot\ln\left(1-\frac{\rho g h_2}{p_0}\right),$$

Again we apply the formula of approximate calculations. For small x there is an approximate equality $\ln(1\pm x)\approx\pm x$ whence

$$\frac{\rho g h_1}{p_0}=\frac{\gamma}{1-\gamma}\cdot\left(-\frac{\rho g h_2}{p_0}\right)$$

from which it is easy to obtain

$$\gamma=\frac{h_1}{h_1-h_2} \qquad (5)$$

Formula (5) is the working one for determine the adiabatic exponent γ.

The order of the work performance.

1. Having opened the valve K_2 (fig. 1). (The valve K_1 is closed), to pump in a cylinder of air so that on the manometer there was a considerable difference of levels of liquid (10 - 15 cm). After closing the valve K_2, wait 2-3 minutes (until the air heated by compression cools down and the levels in the knees of the manometer stop changing). Calculate on a scale the levels of the left and right tubes of the manometer (counting is on the lower edge of the meniscus). Record the difference in h_1 levels.

2. Open and quickly close the valve (valve) K_1 (Fig.3). After 2-3 minutes, record the difference in h_2 levels.

3. By formula (5) calculate the adiabatic exponent $\gamma = C_p / C_v$ for air and compare with the theoretical value, assuming air is a diatomic gas.

4. Repeat the experiment at least 10 times with different manometer readings. Record the results in the table given below. Calculation would be performed by the Student's method. Student's coefficuents $t_{\alpha n}$ one takes from the table given in the instruction to the laboratory work 1.1¸and confidence probability meaning $\alpha = ...$ is noted by teacher. As usual

5. Final result of work would be reprfsented in the form

$$\gamma = \langle \gamma \rangle \pm \Delta\gamma = ... \quad \text{, if } \alpha = ...$$

Table

#	h_1, mm	h_2, mm	h_{1-2}, mm	γ_i	$\langle\gamma\rangle$	$\Delta\gamma_i$	$\Delta\gamma_i^2$	$S_{\langle\gamma\rangle}$	$t_{\alpha n}$	$\Delta\gamma$	E, %
1.											
10.											

Control questions.

1. What process is called isochoric? The same question about adiabatic one.

2. Why for any substance the inequality $C_p > C_v$ takes place?

3. Why the manometer is filled with colored water but not with mercury?

4. How does the duration opening of the valve K_1 affect the result of the experiment accuracy? .

5. In our experiment it is convenient to use the equation of adiabate, which connects the pressure and temperature , and not the equation that connects the pressure and volume. Why is it?

6. Explain the values of air parameters in the cylinder shown in Fig. 3.

7. How will the high humidity in the audience affect the result of the experiment?

8. Solve the problem. Oxygen with mass 80 g is heated isobarically from $15^{\div}C$ to $15^{\div}C$. Determine the work A performed by the gas, its internal energy ΔU changing and the amount of heat supplied Q.by the gas at the process, which is under consideration.

9. Determine: 1) the quantity of ideal gas molecules N_A in one mol (Avogadro number) at the normal conditions; 2) the ideal gas one mol volume V_0 at the normal conditions

10. Considering the air as ideal gas, and that environment is at normal conditions, determine: 1) the final temperature of gas as a result its adiabatic expansion T_1; 2) part of vessel volume V which mentally hightlightly volume V_0 occupies; 3) part of gas mass, which left the vessel as a result of its adiabatic expansion.