

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
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Methodical guidelines
for performance laboratory works
on the subjects

PHYSICS and GENERAL PHYSICS

part 1 **MOLECULAR PHYSICS AND
THERMODYNAMICS**

*(for 1-st year of full-time and part-time students education level “bachelor”
all specialties)*

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INTRODUCTION

Offered methodical pointing contain description of laboratory works in mechanics that students execute at the first year and is destined for all specialties of the Beketov National University of Urban Economy in Kharkiv. They have necessary information on preparation, implementation and accounting about laboratory work.

The primary objective of pointing is intention not only all-round to illustrate the physical phenomena and laws, but also teach a students to look in them and check by an experience way. They must assist at the physical experiment, receive of skills of independent research work and making of abilities to apply theoretical knowledge for analysis and decision of concrete engineering tasks.

The different variants of measuring of the same physical quantities are presented in pointing, due to what a student gets an idea about the variety of methods of physical researches.

Short exposition of concepts, laws is given in every laboratory work. By that it is provided independent study of textbook in the case, when the laboratory work can be executed by a student before reading of corresponding lecture. The special attention is given to the direct measuring and treatment of results. Correctly to estimate their reliability and exactness, it is necessary to know the rules of using basic calculable and measuring devices, bases of the theory of errors. At preparation to laboratory work a student must learn the methodical pointing, and also corresponding theoretical positions, using a textbook or compendium of lectures.

LABORATORY WORK № 1

DETERMINATION OF LENGTH OF FREE PATH LENGTH AND EFFECTIVE DIAMETER OF MOLECULES OF AIR BASING OF ON THE COEFFICIENT INTERNAL FRICTION MEASURING

Objective: define the coefficient of internal friction by method of Poisal and to expect of a middle free path length and effective diameter of molecules of air.

1 Equipment:

1. Vessel with a faucet-dropper and by a capillary, filled with a water.
2. Measuring glass.
3. Glass for collection of water pouring out a vessel.
4. Stop-watch.

2 Generals:

The internal friction force applied to the surface area S of the gas layer (liquid) is determined by the formula

$$F = \eta \left| \frac{d v}{d z} \right| S, \quad (1.1)$$

where η = the coefficient of internal friction, which depends on the nature and state of the substance (for example, temperature); $\frac{d v}{d z}$ = velocity gradient along the z direction, perpendicular to plane S . In the case of gas (liquid) moving along a circular tube, instead of $\frac{d v}{d z}$ one can write $\frac{d v}{d r}$, where r = the distance from the axis of the tube along the radius.

3 Derivation of the calculation formulas

Let us consider the case when the substance in the tube moves at a constant speed. This means that the total sum of all forces acting on the selected cylindrical volume is zero. Such forces will be only two: the force due to the difference in pressure at the various ends of the tube, causing the movement of matter, and the force of internal friction that this motor counteracts.

The first force module has the form

$$F = (p_1 - p_2) \pi r^2, \quad (1.2)$$

where p_1 and p_2 = the pressures at the different ends of the tube. This force should equal the forces of internal friction:

$$F_f = \eta \left| \frac{dv}{dr} \right| 2\pi r l = -2\pi r l \eta \frac{dv}{dr} \quad (1.3)$$

where $2\pi r l$ = the area of the lateral surface of the selected cylinder; the sign " - " on the right side was appeared due to the fact that the derivative $\frac{dv}{dr} < 0$, that is, the velocity decreases with increasing the distance from the axis of the tube.

Equating (1.2) and (1.3), we obtain the differential equation:

$$(p_1 - p_2) \pi r^2 = -2\pi r l \eta \frac{dv}{dr} \quad (1.4)$$

Integrating (1.4), we get

$$v = -\frac{p_1 - p_2}{4\eta l} r^2 + C. \quad (1.5)$$

The constant of integration C should be chosen so that the velocity on the walls will be equal zero ($r = r_0$). This is fulfilled at

$$C = \frac{p_1 - p_2}{4 \eta l} r_0^2. \quad (1.6)$$

Taking into account (1.6), we have an expression for the velocity

$$v(r) = v_0 \left(1 - \frac{r^2}{r_0^2} \right). \quad (1.7)$$

where v_0 = speed on the axis of the tube:

$$v_0 = v(0) = \frac{p_1 - p_2}{4 \eta l} r_0^2 \quad (1.8)$$

Applying (1.7), we can calculate the volume V of a substance passing through the cross section of the tube in time t . If you divide the section of the tube into rings of width dr , then the volume of liquid (gas) will pass through the ring of radius r for time t :

$$dV = 2 \pi r v_0 t \left(1 - \frac{r^2}{r_0^2} \right) dr. \quad (1.8)$$

Let us integrate (1.8) with r in the range from 0 to r_0 :

$$V = \int_0^{r_0} v_0 t \left(1 - \frac{r^2}{r_0^2} \right) 2 \pi r dr = \frac{1}{2} \pi r_0^2 v_0 t \quad (1.9)$$

or, taking into account the expression for v_0 , we obtain the formula

$$V = \frac{p_1 - p_2}{8 \eta l} \pi r_0^4 t \quad (1.10)$$

Poiseuil formula is used to determine the coefficient of internal friction (viscosity) of liquids and gases. By passing a liquid or gas through a tube of a definite radius, measure the pressure drop and volume V . Then, on the basis of the data obtained, calculate η .

Formula (1.10) can be used for gases when not taking into account their compressibility. This condition is fulfilled for small values of the pressure difference

at the ends of the tube: $\frac{p_1 - p_2}{p_2} \ll 1$ as is in this work.

From formula (1.10) we obtain

$$\eta = \frac{\Delta p}{8 V l} \pi r_0^4 t \quad (1.11)$$

Where Δp = pressure difference at the ends of the capillary $\Delta p = p_1 - p_2$; $\Delta p = p_1 - p_2$; r_0 = radius of capillary; l = length of capillary, V = volume of liquid; t = time of flowing of liquid.

Since all values on the right side of formula (1.11) can be measured, this formula can be used to determine the coefficient of internal friction for any gas or mixture of gases.

On the other hand, the kinetic theory of ideal gas establishes a certain correlation between the coefficient of internal friction η , the average free length of gas, the average arithmetic velocity of their motion and the gas density.

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On the other hand, the kinetic theory of ideal gas establishes a certain correlation between the coefficient of internal friction η , the average free length of gas $\bar{\lambda}$, the average arithmetic velocity of their motion \bar{v} and the gas density ρ :

$$\eta = \frac{1}{3} \bar{\lambda} \bar{v} \rho. \quad (1.12)$$

For real gases, this ratio introduces an additional coefficient (approximately equal to 1.5), which depends on the interaction strength between the gas molecules. In this case, formula (1.12) for real gases will look

$$\eta = 0,5 \bar{\lambda} \bar{v} \rho. \quad (1.13)$$

The gas density ρ under these conditions can be determined from the Mendeleev-Clapeyron equation:

$$\rho = \frac{m}{\mu} = \frac{p \mu}{R T} \quad (1.14)$$

where $R = 8,31 \text{ J / mol}$, universal gas constant; $\mu =$ the molar mass of gas; $p =$ pressure; $T =$ absolute temperature; $m =$ mass of gas.

Average arithmetic velocity of gas molecules

$$\bar{v} = \sqrt{\frac{8 R T}{\pi \mu}}. \quad (1.15)$$

Substituting the values of ρ from (1.14) and (1.15) into equation (1.10), we find the mean free path length of gas molecules:

$$\bar{\lambda} = \frac{\eta_{cp}}{p} \sqrt{\frac{\pi R T}{2 \mu}}. \quad (1.16)$$

The average free length $\bar{\lambda}$ and the effective diameter of the gas molecules σ are related by correlation

$$\bar{\lambda} = \frac{l}{\sqrt{2} \pi \sigma^2 n}, \quad (1.17)$$

where σ = the effective diameter of the molecule; n = number of molecules in 1 m^3 under given conditions (temperature and pressure) are founded from the equation

$$n = \frac{p}{k T} \quad (1.18)$$

where $k = 1,38 \cdot 10^{-23}$, Boltzmann constant.

By solving together (1.17) and (1.18), we obtain:

$$\sigma = \sqrt{\frac{k T}{\sqrt{2} \pi \bar{\lambda} p}}. \quad (1.19)$$

All of the above applies to homogeneous gas. The air is a mixture of gases, mainly nitrogen (75.7% by weight) and oxygen (23% by weight). Since these gases are diatomic and close to molar masses ($\mu_{O_2} = 0,028 \text{ kg/mol} = 0,032 \text{ kg/mol}$) and have many other common properties, the formulas given here can also be used for air. Considering all that we may put $\mu = 0,029 \text{ kg/mol}$.

4 Description of the installation and measurement methods

Installation of this laboratory work is located on platform 1, in which a tripod 2 with brackets 3 is mounted (see figure 4.1). The brackets 3 hold a viscometer consisting of a capillary 4 whose radius and length are known and a measuring vessel 5 with a scale of 6 and a cock 7. The vessel 5 is closed by a cork in which the capillary 4 is fixed, which should not touch the surface of the water. When leaking liquid from a measuring vessel 5, the pressure over the liquid decreases and air flows

through the capillary 4 into the vessel. At low velocities of inflow of air in a thin capillary its laminar flow is established. On platform 1, there is a beaker 8 and a metal glass 9.

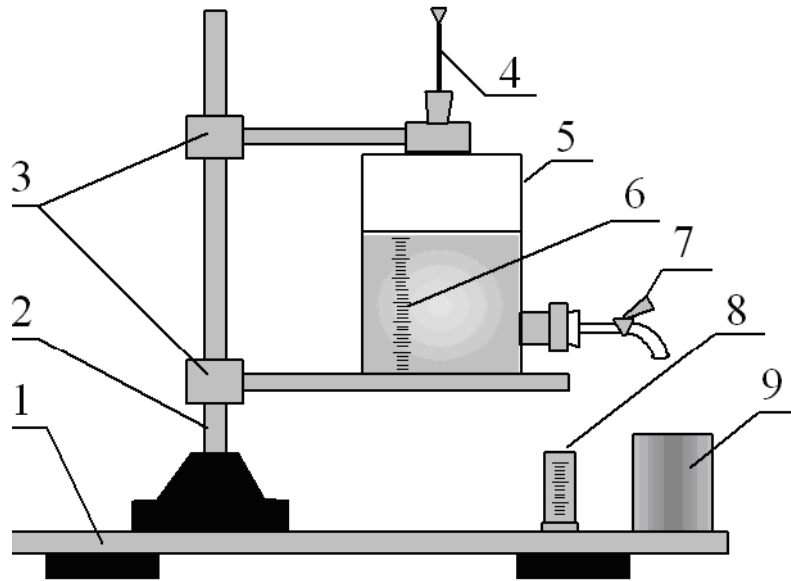


Figure 1.1 Installation for measuring viscosity of air

The opening of the crane is much larger than the capillary section. With a closed valve 7, the air pressure above the liquid inside of the vessel 5 is atmospheric, as the vessel is coupled to the atmosphere through the capillary. As soon as the valve 7 opens, the liquid begins to pour out under its hydrostatic pressure. Until the total pressure of gas and liquid inside of the vessel at the level of the hole will not be equal to the atmospheric, this leakage will be uneven. That is, the condition of uniform leakage is:

$$p_1 + \rho_w g h_1 = p_a \quad (1.20)$$

where p_1 = pressure in the vessel; h_1 = the height of the column of fluid liquid (water); g = acceleration of gravity.

At the same time, at the ends of the capillary, a difference in pressure is established, which causes the air to flow through the capillary into the vessel.

The pressure difference at the ends of the capillary, which is equal $\rho_w g h_1$, changes to over time as the height of the column of fluid decreases. Since the cross-sectional area of the vessel is larger and the volume of the flowing fluid is relatively

small, the change in pressure Δp will be small. Therefore, in formula (1.9) for Δp we can take the average pressure difference at the ends of the capillary in the beginning and at the end of the experiment equal

$$\Delta p = \frac{h_1 + h_2}{2} \rho_e g. \quad (1.21)$$

The volume of gas V passing through the capillary is equal to the volume of liquid flowing into vessel.

5 The sequence of work execution

1. Open the cock and wait until the water starts to drop from the tap. From this moment, put a measuring glass, mark the height of column h_1 of water in the vessel and turn on the stopwatch.

2. When the glass will be -60 cm^3 of water, close the cock and simultaneously stop the stopwatch.

3. Record a new height of a column of water in a vessel h_2 , time t and volume V of water that has flowed out of the vessel.

4. Record parameters of the capillary (r_0, l) temperature and atmospheric pressure in the laboratory (T, p). Measured values, (t, h_1, h_2, V), tabular data, make in table 1.1.

5. Calculate: the pressure difference at the ends of the capillary Δp by the formula (1.21); the coefficient of internal friction η by the formula (1.9); the air density ρ by the formula (1.12); the average arithmetic velocity of air molecules by the formula (1.13); the average free path length of the molecules $\bar{\lambda}$ by the formula (1.14); the concentration of air molecules n by the formula (1.16); the effective diameter of the air molecules σ by the formula (1.17).

6. Calculate the absolute and relative errors of determining the coefficient of internal friction.

Table 1.1 – Results of measuring and calculations

Number of exp.	h_1 , m	h_2 , m	V , m ³	t , s	\bar{v} , m/s	η , Pa s	η_{mean} , Pa s	n , m ³	$\bar{\lambda}$, m	σ , m
1										
2										
3										
4										

6 Checklist questions

1. What are the phenomena and why are called phenomena of transfer?
2. Explain the molecular - kinetic mechanism of viscosity.
3. Explain the physical meaning of the viscosity coefficient. Name the units of its measurement.
4. Write down Poiseul's formula and explain the method of determining the coefficient of viscosity η .
5. What is the free length path?
6. What is the effective diameter of molecules? What does it depend on?
7. What does the average arithmetic speed of gas molecules depend on?
8. How is the concentration of molecules determined?

LABORATORY WORK № 2

DETERMINATION OF INTERNAL FRICTION FACTOR OF LIQUID BY STOKES'S METHOD

Objective: Determination of the internal friction coefficient of fluid by Stokes's method.

1 Equipment:

1. Stokes's device.
2. Lead the balls.
3. Micrometers.
4. Scale ruler.
5. Stopwatch.

2 Stokes's method

The flow of fluid, in which the liquid layers (gas) slide ordered and smoothly along the so-called current lines, is called laminar. If the current is disordered and contains turbulence, this one is called turbulent. The viscosity determines the internal friction that prevents the free flow of fluid. The viscous friction can be imagined as friction between adjacent layers of fluid moving relative to each other.

On the body that moves uniformly in the viscous fluid, the force of internal friction acts. The stream that flows around the body is laminar. It was found experimentally that the force of internal friction is directly proportional to the velocity of the object:

$$f = kv. \quad (2.1)$$

The value of the coefficient k depends on the size and shape of the body, as well as on the viscosity of the liquid (gas). In particular, Stokes showed theoretically that when a ball falls in an infinite fluid, if there is no turbulence (a small ball dropping at a low velocity), the frictional force acting on it is expressed by the formul:

$$f = 6\pi r\eta v. \quad (2.2)$$

On a solid ball in a viscous fluid, there are three forces: the force of gravity, the pushing force of Archimedes, the strength of the resistance of the movement (figure 2.1):

$$P = m g = \rho V g = \frac{4}{3} \pi r^3 \rho g;$$

$$P_1 = m_1 g = \rho_1 V g = \frac{4}{3} \pi r^3 \rho_1 g,$$

where ρ_1 = liquid density; ρ = the density of the ball.

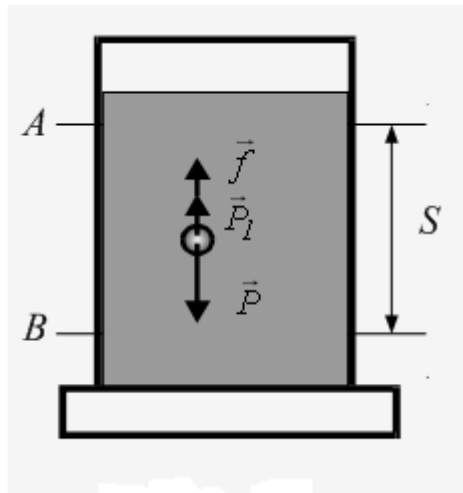


Figure 2.1 – Forces applying to a ball

When moving the ball, a layer of liquid that borders on its surface, adheres to it and moves with the velocity of the ball. The adjacent layers of fluid are also beginning to move. The resulting speed is smaller, the further they are from the ball. Thus, when calculating the resistance of the medium, it is necessary to take into account the friction of separate layers of fluid between themselves, and not friction between a ball and a liquid.

In the event of a ball falling, all forces are directed vertically: the force of gravity - down; pushing force and resistance force - upward. The strength of the resistance \vec{f} due to the high initial velocity of the ball is initially maximal. Over time,

the movement of the ball slows down and reaches such a speed at which all three forces will be balanced. Such a motion is called stationary. In this case, the ball moves in inertia at a constant velocity v_0 . For this case we have.

$$\frac{4}{3} \pi r^3 \rho g - \frac{4}{3} \pi r^3 \rho_l g - 6 \pi r \eta v_0 = 0 \quad (2.3)$$

Solving the equation (2.3) with respect to the coefficient of internal friction η , we obtain:

$$\eta = \frac{2}{9} \frac{\rho - \rho_l}{v_0} g r^2 = \frac{2}{9} \frac{\rho - \rho_l}{S} g r^2 \tau \quad (2.4)$$

where S = the path that the ball has passed in τ seconds.

Realizing the drop of a ball in an infinite environment in a laboratory environment is impossible, because the liquid is always contained in any vessel that has walls. Given the presence of walls when moving the ball along the axis of the cylinder leads to the expression

$$\eta = \frac{1}{18} g d^2 \frac{(\rho - \rho_l) \tau}{S \left(1 + 2,4 \frac{d}{D} \right)} \quad (2.5)$$

where D = the diameter of the cross-section of the cylinder; d = the diameter of the ball.

The coefficient of internal friction depends on the temperature. In this regard, recording the value of the coefficient of internal friction of the liquid to be studied, it is necessary to indicate the temperature. The temperature values are measured using a laboratory thermometer.

3 Consistency performance of the work

1. With a micrometer to measure the diameter of the balls in three places and determine the average value d .

2. Measure the diameter of the balls and dip it in liquid. The eye of the observer must be located in front of the upper mark A. Determine the time τ , during which the ball is moving uniformly segment S passing the path between marks A and B (see figure 2.1).

3. Measure by scale ruler the distance S between marks. Repeat experiment with another balls.

4. Measured values (S, τ , d) swing to table 2.1, write tabular data ρ , ρ_1 .

Table 2.1 – Results of measuring and calculations

No	d , mm	d_{av} , mm	Δd , mm	S, cm	ΔS , cm	τ , s	$\Delta \tau$, s	η , Pa.s	η_{av} , Pa.s	$\frac{\Delta \eta}{\eta}$, %	$\Delta \eta$, Pa.s					
1																
2																
3																
4																

5. According to the formula (2.5) calculate η .

$$\eta = \frac{1}{18} g d^2 \frac{(\rho - \rho_1) \tau}{S} \quad (2.6)$$

6. Calculate the absolute and relative error of determination η , counting η function of the (S, τ, d) .

4 Checklist questions

1. What are the effects and what are called transfer phenomena?
2. Write down and explain the diffusion equation and the internal friction.
3. Explain the physical meaning of the diffusion coefficient and the coefficient of internal friction. What are their units in S I.
4. Bring the coefficients D and η , according to the molecular-kinetic theory of gases.

LABORATORY WORK № 3

DETERMINATION OF THE GAS INDEX ADIABATE

Purpose: Determination the ratio of the heat capacity of the gas at constant pressure C_p to the heat capacity of the gas at a constant volume C_v and the change in the entropy of an ideal gas in the isochoric process.

1 Equipment:

1. Glass bottle
2. Water manometer.
3. Pump.

2 General provisions

Along with isochoric, isobaric and isothermal processes in thermodynamics, processes that occur in the absence of heat exchange with surrounding bodies are often considered. Containers with heat-impermeable walls are called adiabatic shells, and the processes of expansion or compression of gas in such vessels are adiabatic.

In the adiabatic process, $\Delta Q = 0$, so the first law of thermodynamics takes the form

$$A = -\Delta U ,$$

that is, gas performs obtained work to internal energy.

In the diagram (p, V), the process of adiabatic expansion (or compression) of gas is depicted by a curve called an adiabat. In the case of adiabatic expansion, the gas carries out positive work ($A > 0$); so its internal energy decreases ($\Delta U < 0$). This leads to a decrease in the temperature of the gas. As a result, gas pressure with adiabatic expansion decreases faster than with isothermal.

The ratio $\gamma = \frac{C_p}{C_v}$ is in the Poisson equation, which describes the state of gas in an adiabatic process. The value of γ has the name of the adiabatic index.

In this work, the relation γ is determined by the Clement-Disorma method, which is based on the use of equations that describe the adiabatic and isothermal transitions between gas states.

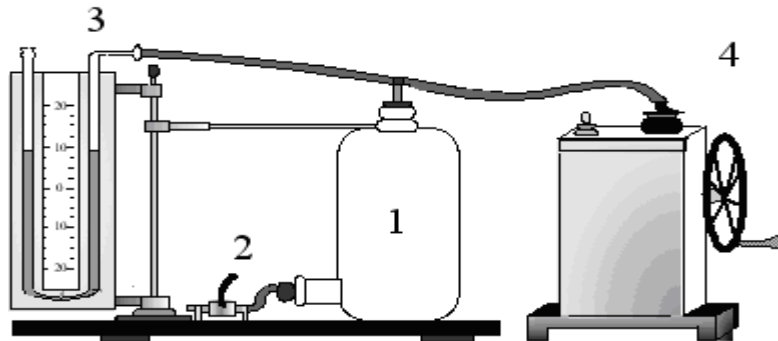


Figure 3.1 – Setting for measuring adiabatic index

Consider the essence of the method. The glass cylinder 1 (see figure 3.1), which is coupled to the atmosphere through the tube with the tap 2, is filled with air at room temperature T_1 and atmospheric pressure P_0 . The pressure in the cylinder 1 can be controlled with the help of a pressure gauge 3. With the help of a pump, a small portion of air is pumped into the cylinder, which causes an increase in pressure in the cylinder. If the pumping is carried out quickly, then during this time, there is no heat exchange between the gas in the cylinder and the environment. It must pass some time (2 - 3 minutes) to make the temperature in the tank equal to the temperature of the environment T_1 . At the same time, the pressure in the tank will be somewhat reduced:

$$P_1 = P_0 + \rho g h_1,$$

where h_1 = the difference in fluid levels in the pressure gauge; ρ = the density of the liquid.

In order to use the equations that describe different processes (adiabatic, isochoric, isothermal) in gas in the course of the experiment, they are construed as follows.

We separate in the middle of the cylinder an arbitrary, sufficiently large portion of air, which occupies a slightly smaller volume than the entire cylinder with tubes.

With a slight change in the total amount of air when it is released through the tap K , the amount of air in the selected portion remains unchanged

In various processes, the gas contained inside the closed surface will expand and compress, performing work and exchanging heat with ambient gas. Since the kinetic energy of the emerging macroscopic motion is small, these processes can be considered as quasi-static. The graphs of the processes are shown in figure 3.2. Process 1–3 is isothermal, the process 1–2 is adiabatic.

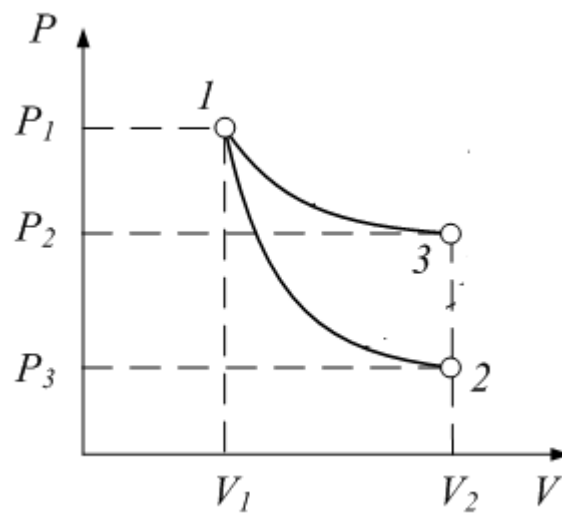


Figure 3.2 The graphs of isothermal 1–3 and adiabatic 1–2 processes

Let the first state of the allocated portion of the gas is characterized by the parameters P_1 , T_1 , V_1 (see fig. 2.3, a). For the adiabatic transition to the second state, for a short time, open the tap K and release a small amount of air (its value is determined by the difference between the levels h_1 , and the section of the tube of the manometer, until the pressure in the cylinder will be equal to the atmospheric. This will be the second state (see fig. 3.3, b).

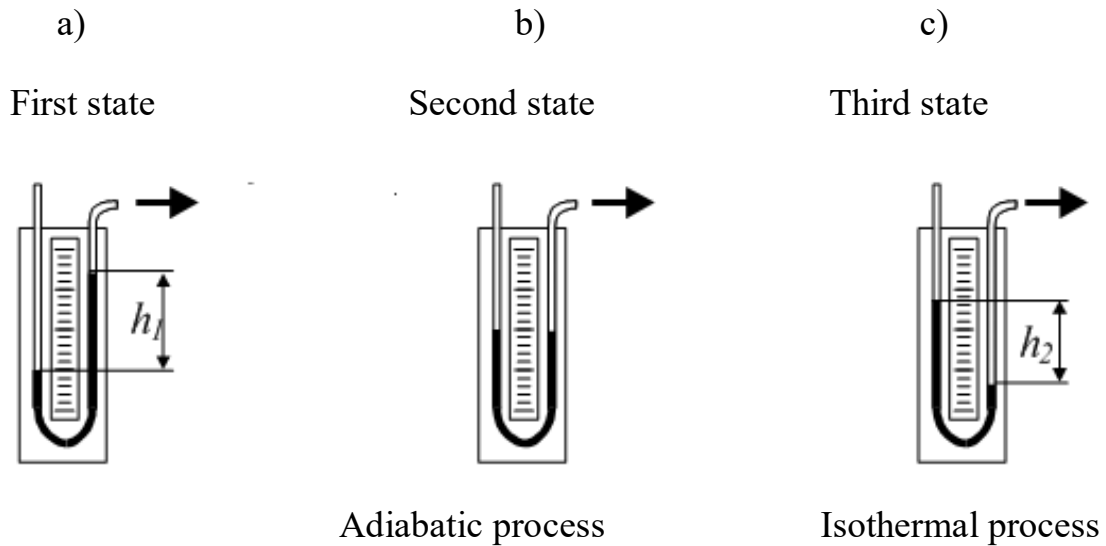


Figure 3.3 – Successive states of the system

Its parameters $P_2 = P_0$, V_2 , T_2 .

Adiabatic expansion with a decrease in temperature and pressure at transition $1 \rightarrow 2$ can be described by equation

$$P_1 V_1^\gamma = P_2 V_2^\gamma. \quad (3.1)$$

Then, spontaneously, without the influence of the experimenter, there is heat exchange with the environment until the temperature in the cylinder becomes equal to the temperature of the environment, and the pressure will not cease to change and will reach the maximum value. This will be determined by the difference in fluid levels in the pressure manometer h_2 . Thus, the system has moved into the third state, which is described by the following parameters (figure 3.3, c):

$$P_3 = P_0 + \rho g h_2.$$

With a sufficiently large volume of the cylinder and a small section of the tube of the pressure gauge, it can be neglected by its volume in the transition from the state 2 to the state 3 and to put ($V_3 = V_2$). So we may also assume that the heating only leads to an increase in pressure, and the transition $2 \rightarrow 3$ is isochoric. Let's estimate this assumption.

Now you can go to the direct determination of the value of γ . Assuming that the gas in the first and the third states has the same temperature T_1 , we write the parameters of these states in accordance with the Boyle-Mariotte law

$$\frac{P_1}{P_3} = \frac{V_3}{V_1}. \quad (3.2)$$

Taking into account that $V_3 = V_2$, we expose the expression (3.2) to the degree γ :

$$\left(\frac{V_2}{V_1}\right)^\gamma = \left(\frac{P_1}{P_3}\right)^\gamma. \quad (3.3)$$

Compeering expressions (3.1) and (3.3) gives

$$\left(\frac{V_2}{V_1}\right)^\gamma = \frac{P_1}{P_2}. \quad (3.4)$$

Equating the right-hand sides of expressions (3.3) and (3.4), we obtain:

$$\frac{P_1}{P_2} = \left(\frac{P_1}{P_3}\right)^\gamma,$$

and taking into account that $P_1 = P_0 + \rho g h_1$, $P_2 = P_0$, $P_3 = P_0 + \rho g h_2$,

we will have:

$$\frac{P_0 + \rho g h_1}{P_0} = \left(\frac{P_0 + \rho g h_1}{P_0 + \rho g h_2}\right)^\gamma \quad (3.5)$$

Let's transform the right part of expression (3.5), assuming $\rho g h_1$ and $\rho g h_2$ to be considerably smaller than P_0 :

$$\left(\frac{P_0 + \rho g h_1}{P_0 + \rho g h_2}\right) = \frac{(P_0 + \rho g h_2 + \rho g h_1 - \rho g h_2)^\gamma}{(P_0 + \rho g h_2)} =$$

$$= \left[1 + \frac{\rho g (h_1 - h_2)}{P_0 + \rho g h_2} \right]^\gamma = 1 + \gamma \frac{\rho g (h_1 - h_2)}{P_0}. \quad (3.6)$$

Substituting the last expression in the right-hand side of equation (3.5), we obtain:

$$1 + \frac{\rho g h_1}{P_0} = 1 + \gamma \frac{\rho g (h_1 - h_2)}{P_0}, \quad (3.7)$$

or

$$\gamma = \frac{h_1}{h_1 - h_2}. \quad (3.8)$$

Note, that in expression (3.6) we neglected the value of $\rho g h_2$ in comparison with P_0 and used the expansion of functions $(1 + x)^n$ in a series:

$$(1 + x)^n = 1 + n x + \frac{n(n-1)}{2!} x^2 + \dots$$

For small x it is possible to use only the linear part of the equation. Thus, the experimental determination of $\gamma = C_p/C_V$ reduces to the measurement of h_1 and h_2 . Let us estimate the approximation $V_3=V_2$. Since the change in temperature, pressure and air volume is very small, for simplicity it is possible to treat them as infinitesimal quantities, that is, differential ones. From the equation Mendeleev - Clapeyron:

$$P dV + V dP = \frac{m}{\mu} R dT. \quad (3.9)$$

In case of transition, $2 \rightarrow 3$ let us replace dV by $V_3 - V_2 = \Delta V$, and dP by $\Delta P = P_3 - P_2 = \rho g h_2$.

In order to consider the transition process $2 \rightarrow 3$ isochoric, in equation (3.9) it is necessary to neglect the components of $P\Delta V$ in comparison with $V\Delta P$. Their attitude is

$$\frac{P \Delta V}{V \Delta P} \approx \frac{\frac{1}{2} P_0 h_2 S}{V \rho g h_2} = \frac{\rho g h_0 h_2 S}{2 V \rho g h_2} = \frac{h_0 S}{2 V}. \quad (3.10)$$

Here h_0 = difference of levels of a liquid in a pressure gauge which would be at atmospheric pressure; V = volume of air in the cylinder; S = section area of the manometer tube.

As can be seen from expression (3.10), the approximation will be the more likely, the greater is the density of the liquid (while decreasing), the smaller section of the tube and the larger the volume of the cylinder. So, for $h_1 = 10 \text{ m}$ (for a liquid whose density is close to the water density). $S = 1 \text{ cm}^2 = 10^{-4} \text{ m}^2$,

$$V = 5 \cdot 10^{-3} \text{ m}^3, \quad \frac{h_0 S}{2 V} = 0,1.$$

Change of entropy at isochoric heating of the air in the cylinder (transition 2 → 3):

$$\Delta S = C_v \frac{m}{\mu} \ln \frac{T_3}{T_2}$$

where m = mass of air in the tank; $\mu = 0,029 \text{ kg/mol}$ - the molar mass of air, and

$$C_v = \frac{i}{2} R, \quad i = 5.$$

$$\frac{T_3}{T_2} = \frac{P_3}{P_2} = \frac{P_0 + \rho g h_2}{P_0} = 1 + \frac{\rho g h_2}{P_0}; \quad \Delta S = C_v \frac{m}{\mu} \ln \left(1 + \frac{\rho g h_2}{P_0} \right).$$

Due to the small value of h_2 , the following simplification may be done when calculating ΔS . We will assume that P_0 is the normal atmospheric pressure ($P_0 = \rho g h_0$ where $h_0 = 10,33 \text{ m}$).

$$\frac{m}{\mu} = \frac{\rho_{\text{ног}} V}{\rho_{\text{ног}} V_0} = \frac{V}{V_0}, \quad \ln \left(1 + \frac{h_2}{h_0} \right) \approx \frac{h_2}{h_0}.$$

Taking this into account, we obtain a working formula for determining ΔS :

$$\Delta S = \frac{i}{2} R \frac{V}{V_0} \frac{h_2}{h_0}, \quad (3.11)$$

where V = volume of air in the cylinder; $V_0 = 22,4 \cdot 10^{-3} \text{ m}^3$, volume of 1 mol of gas under normal conditions.

3 Consistency performance of the work

1. To conduct for help to the pump of air-blasting in a bulb to pressure that answers the difference of levels in a manometer a 20-25 cm (to air-blast carefully).

2. To wait, while the temperature of air in a bulb will attain the temperature of T_1 of environment. To measure the difference of levels of h_1 , that set.

3. To open a faucet 2 (see figure 3.1) for a while. Speed of declamping must be such, that in first moment, when even liquids will stop in a manometer, a report with atmospheric air was stopped. In the moment of opening of faucet air broadens, pressure of him in a bulb becomes even atmospheric P_2 (at opening of faucet from the dramatic change of pressure of air in a bulb possible origin of vibrations of liquid that quickly ceases and does not influence on motion of experience).

4. To wait, while air in a bulb, that grew cold at adiabatic expansion, will be heated to the room temperature of T_1 . To measure the difference of levels of manometer of h_2 , that set.

5. To repeat experience 8-10.

6. To bring the results of measuring to the table. 3.1.

Table3.1 – Results of measuring and calculations

No exp.	h_1 , cm	h_2 , cm	Δh_1 , cm	Δh_2 , cm	$\gamma = \frac{h_1}{h_1 - h_2}$	ΔS , J/K
1						
2						
3						
4						
5						
6						
7						
8						

4 Checklist questions

1. What parameters characterize the state of a given mass of gas?
2. What is called pressure? What is the unit of pressure?
3. What process is called isobaric, isochoric, isothermal? Which laws determine the state of gas in these processes?
4. Write down the Mendeleev – Clapeyron equation for 1 mole and for an arbitrary one mass of gas.
5. What process is called adiabatic?
6. How and why the temperature of the gas in the vessel changes when conducting experience?
7. Explain the physical content of heat capacity.
8. Which heat capacity is greater -1. What parameters characterize the state of a given mass of gas?
9. Which is the relation between C_p and C_v ?,

LABORATORY WORK № 4

RESEARCHES OF THE PHENOMENON OF SUPERFICIAL STRETCHING OF LIQUID

Purpose of work is measuring of coefficient of superficial stretching of liquid by the methods of tearing away of ring

1 Devices and equipments:

1. Rings are on the suspension Teresa Zholi.
2. Rings are on the suspension
3. Wheights.
4. Burettes are with faucets.
5. Probed liquid.
6. Vessel for drops.

2 Generals

On a molecule, located into a liquid, forces of intermolecular interaction operate from the side of molecules which surround it. In average this influence is compensated and molecule, being in the field of molecular forces, has no certain direction of operating on it force. The density of pair and gas above a surface far less than density of liquid, that is why influence from the side of molecules of gas on the molecule of superficial layer is almost absent. Thus, the uncompensated force, directed inward liquids, acts on a molecule. Such force is named by force superficial stretching. The presence of this force results in appearance of additional potential energy of superficial layer. The state of equilibrium corresponds to minimum of potential energy, that is why in default of external forces a liquid takes form with a minimum surface, that is form a ball. Coefficient of superficial stretching of liquid is determined by work which must to be done by forces of superficial stretchin, to form a surface on bound of liquid or gas

$$\alpha = \frac{d A}{d S} \quad (4.1)$$

and measured in J/ m². The coefficient of superficial stretching can be also defined as force, acting on any element of the liquid surface line:

$$\alpha = \frac{F}{L}. \quad (4.2)$$

3 Method of tearing away of ring

Setting for determination of coefficient of superficial stretching of water by the method of tearing away of ring, represented on figure 4.1 (scales of Zholi). Thin-walled ring 2 (it is made from material which well moistens the probed liquid) is suspended on a spring 3, situated on the platform 1. The pendant of ring is executed thus, that his axis was vertical. Spring 3 fastened on a bracket 4, hardly connected with a barbell 5. Lengthening of spring 3 (and the force of its stretching) it is possible to measure by a scale 6, if preliminary graduated a spring. Let us bring from below a vessel with water 7 to the ring and heave up a vessel 8, that a ring a bit touched the surface of water.

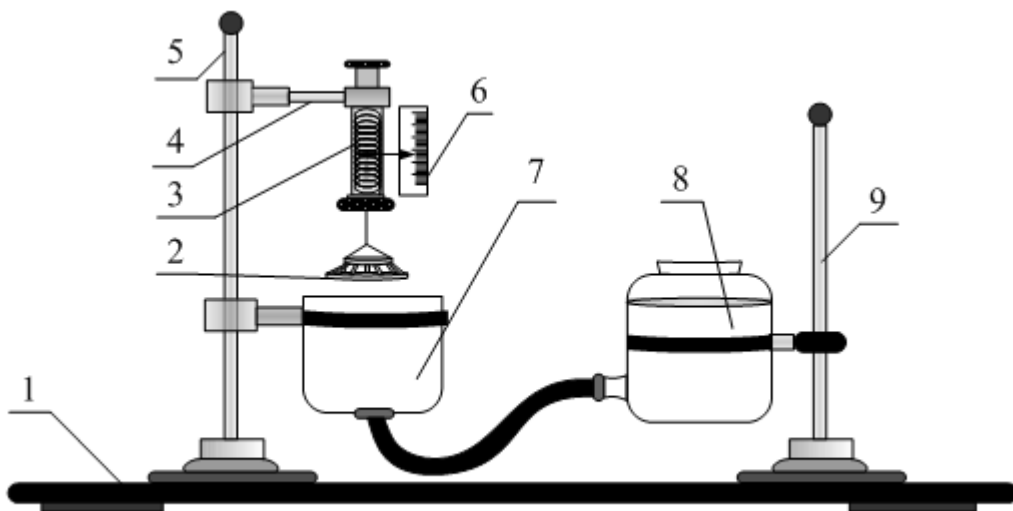


Figure 4.1 – Setting for determination of coefficient of superficial stretching

Thus water will begin to rise on the walls of ring, and a ring will a bit drop inward liquids. This effect can be noticed at the small stretch of spring in moment, when a ring will touch the surface of water. If after it will begin slowly to drop a

vessel with water, a spring will be stretched, while ring 2 do not tear away from the surface of water. Thus the break of superficial tape will take place for both sides of contour of ring. If to measure force of broken F_B , which must be attached to the ring, to tear superficial tape, and calculate the internal and external contours of ring πD_1 and πD_2 (they are the contours of break), it may define the coefficient of superficial stretching of water after a formula

$$\alpha_B = \frac{F_B}{\pi D_1 + \pi D_2} = \frac{F_B}{\pi (D_1 + D_2)}, \quad (4.3)$$

where D_1 i D_2 = internal and external diameters of ring.

Denote by h the thickness of the ring's wall, then $D_1 = D_2 - 2h$ and

$$\pi (D_1 + D_2) = \pi (D_2 - 2h + D_2) = 2\pi (D_2 - h).$$

Substituting these transformations in (4.3), we obtain:

$$\alpha_B = \frac{F_B}{2\pi (D_2 - h)}. \quad (4.4)$$

In the case of two or more rings, the expression for the coefficient of surface stretching

$$\alpha_B = \frac{F_B}{2\pi \left[\sum_{i=1}^n D_i - n h \right]}, \quad (4.5)$$

For four rings (as it is in the given laboratory setting) it can obtain for the force of stretching

$$\alpha_B = \frac{F_B}{2\pi (D_1 + D_2 + D_3 + D_4 - 4h)}, \quad (4.6)$$

where D_1, D_2, D_3, D_4 = external diameters of rings. In the moment of broken F_B is equal to the force of stretching.

4 To execute the graduation of spring.

1. First it is necessary to define and write down the zero position of counting out scale. In future, using the sets of weights from 1 to 10 grammes (through a 1 gram) and loading by them scales, to determine counting out, which answer lengthening of spring and to bring results to the table 4.1.

2. From data of table. 4.1 build a chart how it is demonstrated in figure 4.2: for abscise axis does put aside loading of P and for y -axes – absolute lengthening of spring Δx .

Table 4.1 – Dependance lengthening of the spring on the loading

$P, 9,81 \cdot 10^{-3} \text{ N}$	0	1	2	3	4	5	6	7	8	9	10
$x, \text{ mm}$											
$\Delta x = x - x_0, \text{ mm}$											

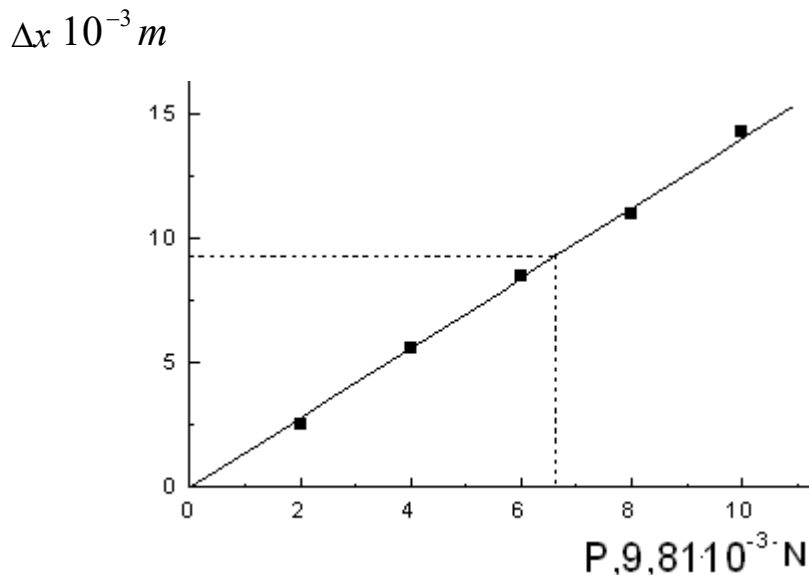


Figure 4.1 – Chart demonstrating absolute lengthening of spring Δx on th loading P

3. To heave up the vessel of D so that to provide the touch of lower edge of ring with the surface of liquid (water) in a vessel. As a metallic ring is contained

forces of superficial stretching of liquid, it will stretch a liquid at lowering of vessel 8, and the spring will begin to stretch. When the force of superficial stretching of liquid and force of lengthening of spring will become identical in magnitude, tearing away of rings will take place from its surface. In the moment of tearing away it is needed to mark position of aim on the scale. This experience needs to be repeated once or twice. To bring the results of measurements in a table. 4.2. Finding the mean arithmetic value of value of lengthening of spring $\langle \Delta x_B \rangle$ after a calibration chart (see figure 4.1 the dotted line) to find force P , after the force F_B . Using a formula (4.4), to calculate the coefficient of superficial stretching of water α_g .

Table 4.2 - Results of measuring the position of aim on the scale at the tearing away of rings

№ exp.	x_0 , mm	x_B , mm	$\Delta x_B = x_B - x_0$, mm	$\langle \Delta x_B \rangle$, mm	F , N	α , N/m	$\Delta \alpha$, N/m	$\Delta \alpha / \alpha$, %
1								
2								
3								
4								
5								

4. Calculate absolute and relative errors at determination α .

5 Control questions

1. Explain the causes of the appearance of forces of surface stretching, based on the molecular - kinetic theory.
2. Explain the physical content of the coefficient of surface stretching.
3. In which units of SI is measured α ?
4. Write the working formulas for determining α by the methods of tearing away of ring.
5. Explain what does the surface stretching coefficient depend on?

Виробничо-практичне видання

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до виконання лабораторних робіт
з курсу

«ФІЗИКА» та «ЗАГАЛЬНА ФІЗИКА»

ЧАСТИНА 1 МОЛЕКУЛЯРНА ФІЗИКА ТА ТЕРМОДИНАМІКА

*(для студентів 1 курсу денної та заочної форм навчання
освітнього рівня «бакалавр» усіх спеціальностей)*

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