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METHODOLOGICAL GUIDE FOR LABORATORY WORK IN PHYSICS

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Reviewer: Ph.D., Assoc. Zhamangulov A.A.

Compiled by: Muratalieva V.Zh., Manzhikova S.Ts., Ismailova B.I.

This manual for laboratory work in medical physics is compiled in accordance with the program of the medical physics course for higher educational institutions. Its purpose is to assist students in understanding the theoretical material being studied and in working with various physical devices, as well as to familiarize them with the elements of conducting a physical experiment. Each work contains brief theoretical information, a description of the laboratory setup, then the procedure for performing the work, recommendations for statistical processing of the results and control questions.

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PREFACE

Dear students!

One of the disciplines studied in the first year at medical universities is the discipline "Physics". Physics is a field that constantly surrounds us in everyday life. Every day, the influence of physics on the development of medicine is only increasing, and the medical industry is being modernized due to this. The application of physics to medicine is undeniable. In fact, every tool used by doctors, from the scalpel to the most sophisticated devices for making an accurate diagnosis, functions or is made thanks to advances in the world of physics. It is worth noting that physics in medicine has always played an important role.

The purpose of studying this discipline is to create a theoretical basis for understanding a number of processes occurring in a living organism, the result of the influence of external factors, such as electric fields, sound waves on the human body, as well as for understanding the principles of operation of medical and diagnostic equipment.

You need this study guide to complete the lab. It indicates the terms, physical laws and formulas that you must know in order to correctly perform the experiment, which tables for recording experimental data should be prepared in a notebook.

For the successful development of laboratory classes, we recommend the following sequence of actions when performing laboratory work:

1. Write in a notebook: the topic, the purpose of the work, instruments and accessories.
2. Write a brief summary of the theoretical part of the laboratory work.
3. Review the progress of the lab.
4. Do an experiment.
5. Draw tables and fill them with the necessary experimental data.
6. Perform processing of the received data. Write the calculations in the report.
7. Record the output.
8. Answer the control questions in writing.

We wish you success!

PROCESSING THE RESULTS OF THE STUDY OF A PHYSICAL EXPERIMENT

The purpose of the work: To study elementary estimates of measurement errors of physical quantities obtained from the experiment. Learn how to correctly process experimental data in laboratory work, draw up the results of the experiment

Theoretical introduction

The exact natural sciences are based on measurements. By measuring some physical quantity, we do not expect to get its true value. Therefore, it is necessary to somehow indicate how close the indicated result can be to the true value, i.e. indicate the accuracy of the measurement. To do this, together with the result obtained, indicate the approximate measurement error.

If the measurement consists in comparing a given quantity with another, homogeneous quantity, taken as a unit, then the measurement in this case is called direct.

Direct (immediate) measurements are those measurements in which we obtain the numerical value of the measured quantity either by direct comparison with a measure (standard), or with the help of instruments calibrated in units of the measured quantity. For example, measuring length with a ruler, time with a stopwatch, etc.

However, such a comparison is not always made directly. In most cases, it is not the quantity of interest to us that is measured, but other quantities associated with it by certain relationships and patterns. In this case, to determine the required quantity, it is necessary to first measure several other quantities, from the values of which to calculate the value of the required quantity. Such a measurement is called *indirect* .

Indirect measurements consist of direct measurements of one or more quantities associated with the quantity being determined by a quantitative dependence and the calculation of the quantity to be determined from these data.

Measuring instruments are always involved in measurements, which put one value in correspondence with another associated with it, accessible to the quantitative assessment of our senses.

For example, the current strength is associated with the angle of deviation of the arrow on the scale with divisions. In this case, two basic conditions for the measurement process must be met: unambiguousness and reproducibility of the result. These two conditions are always satisfied only approximately. Therefore, the measurement process contains, along with finding the desired value, and an estimate of the measurement inaccuracy.

The value of the measurement error of a certain quantity X is usually characterized by absolute and relative errors.

1. ***Absolute error*** is the difference between the experimentally found (measured) and the true value of a certain quantity:

$$\Delta X = X_{meas} - X_{true}. \qquad (1)$$

2. ***Relative error*** is the ratio of the absolute error to the true value of the measured quantity X :

$$\varepsilon_X = \frac{\Delta X}{X_{true}}. \qquad (2)$$

The quality of measurement results of a certain value is characterized by a relative error. ε_x can be expressed as a percentage.

Speaking about measurement errors, at first should mention about *gross errors* (misses) arising as a result of an oversight by the experimenter or a malfunction of the equipment.

Gross mistakes should be avoided. If it is determined that they have occurred, the corresponding measurement should be discarded. To eliminate misses, any measurements must be repeated at least two times.

Experimental errors not related to misses are divided into random and systematic.

A systematic error is an error that remains constant or regularly changes when measurements are repeated. The most significant reasons for the occurrence of systematic errors are the imperfection of measuring instruments - instrumental error and incomplete consideration of the experimental conditions - methodological error.

Instrumental errors can be most easily assessed if they are related to the design features of the instruments themselves. These errors are indicated in the passports for the devices. For many electrical measuring instruments, their accuracy class is indicated directly on the scale.

The accuracy class of the instrument γ is the ratio of the absolute error of the instrument ΔX_{appr} to the maximum value of the measured value X_{max} , which can be determined using this device (this is the systematic relative error of this device, expressed as a percentage of the nominal scale X_{max}):

$$\gamma = \frac{\Delta X_{appr}}{X_{max}} \cdot 100\%$$

Then the absolute error ΔX_{appr} of such a device is determined by the relation:

$$\Delta X_{appr} = \frac{\gamma \cdot X_{max}}{100\%}$$

For electrical measuring instruments, 8 accuracy classes have been introduced: 0.05; 0.1; 0.5; 1.0; 1.5; 2.0; 2.5; 4. Instruments of accuracy class 0.05; 0.1; 0.2; 0.5, are used for accurate laboratory measurements (precision).

The closer the measured value is to the nominal value, the more accurate the measurement result will be. The maximum accuracy (i.e., the smallest relative error) that a given instrument can provide is equal to the accuracy class. This circumstance must be taken into account when using multi-scale instruments.

The scale must be chosen in such a way that the measured value remains within the limits of the scale, being as close as possible to the nominal value.

If the accuracy class for the device is not specified, then the following rules must be followed:

- The absolute error of devices with a vernier is equal to the accuracy of the vernier.
- The absolute error of devices with a fixed pointer pitch is equal to the division value. *The division* value is the measurable value that causes the pointer to deviate by one division. The price of division is defined as the ratio of the upper limit of the measurement of the device to the number of divisions of the scale.
- The absolute error of digital instruments is equal to the unit of the minimum digit.
- For all other devices the absolute error is assumed to be equal to half the division value

Methodical errors are caused by the shortcomings of the applied measurement method, the imperfection of the theory of a physical phenomenon, and the inaccuracy of the calculation formula used to find the measured value.

Random error - an error that changes randomly when repeating equally accurate measurements.

Random errors are involuntarily introduced by the experimenter due to the imperfection of the sense organs, random external factors, etc. if the error of each individual measurement is fundamentally unpredictable, then they randomly change the value of the measured quantity. These errors are statistical in nature, they can only be estimated by statistical processing of multiple measurements of the desired value.

It has been established that with a very large number of measurements, the probability of obtaining one or another result in each individual measurement can be determined using the normal Gaussian distribution. With a small number of measurements, the mathematical description of the probability of obtaining one or another measurement result is called Student's distribution.

Calculation of errors in direct measurements

Let, when measuring some quantity X , we get n results: X_1 , X_2 , ...,X_n . The arithmetic mean of a series of measurements is closer to the true value of the measured value than most individual measurements. The following algorithm is used to obtain the measurement result of a certain value X.

1. The arithmetic mean of a series of n direct measurements is calculated:

$$X_{average}=\frac{1}{n}\sum_{i=1}^{n} X_i$$

2. The absolute random error of each measurement ΔX_i is calculated - is the difference between the arithmetic mean of a series of direct measurements and the given measurement:

$$\Delta X_i = X_{av} - X_i$$

3. The mean square absolute error S_X is calculated :

$$S_X=\sqrt{\frac{\sum_{i=1}^{n} (\Delta X_i)}{n(n-1)}}$$

4. The absolute random error ΔX_{random} is calculated . With a small number of measurements, the absolute random error can be calculated through the root-mean-square error S_x and Student's coefficient $t_{\alpha, n}$:

$$\Delta X_{random} = t_{\alpha, n} \cdot S_X .$$

Student's coefficient depends on the number of measurements *n* and the reliability factor α (Table 1 shows the dependence of the Student's coefficient on the number of measurements for a fixed value of the reliability coefficient $\alpha = 0.95$).

The reliability factor α is the probability with which the true value of the measured value falls within the confidence interval.

Confidence interval $[X_{av} - \Delta X; X_{av} + \Delta X]$ **is** a numerical interval in which the true value of the measured quantity falls with a certain probability **.**

So, ***the Student's coefficient*** is the number by which the root-mean-square error must be multiplied in order to ensure the specified reliability of the result for a given number of measurements. The greater the reliability required for a given number of measurements, the greater the Student's coefficient. On the other hand, the greater the number of dimensions, the less Student's coefficient for a given reliability.

In the laboratory work of our workshop, we will consider the reliability to be given and equal to 0.95. The numerical values of the Student's coefficients for this reliability for a different number of measurements are given in Table 1.

Table 1 .

Number of measurements *n*	2	3	4	5	6	7	8	9	10	11	12
Student's coefficient, $t_{a,n}$	12.7	4.3	3.18	2.78	2.57	2.45	2.36	2.31	2.26	2.23	2.20

5. Find the relative error

$$\varepsilon_X = \frac{\Delta X}{X_{av}} \cdot 100\% .$$

6. The error is rounded off and the result is recorded. Since the measurement result is presented as an interval of values, the value of which is determined by the total absolute error, the correct rounding of the result of the error is important. Rounding starts with an absolute error. The number of significant digits that is left in the error value

generally depends on the safety factor and the number of measurements. However, even for very accurate measurements, in which the exact value of the error is important, do not leave more than two significant figures.

In laboratory work, as a rule, a small amount of measurement is carried out, therefore, when rounding (with an excess) of the total absolute error, one significant figure is left.

The digit of the significant digit of the absolute error determines the digit of the first doubtful digit in the result value. Therefore, the value of the result itself must be rounded (corrected) to that significant figure, the digit of which coincides with the digit of the significant digit of the error. The formulated rule should be applied in cases where some of the digits are zeros.

For example, if we measure the length of a segment, we get the following result: l_{av} = 2.34582 cm and $\Delta\ell$ = 0.02631 cm. How to record the result of measuring the length of a segment?

First, we round up the absolute error with an excess, leaving one significant figure $\Delta\ell$ = 0.02631 ≈ 0.03 cm. The significant figure of the error is in the hundredth place. Then we round the average value with a correction to the nearest hundredth, i.e. to that significant digit, the digit of which coincides with the digit of the significant digit of the error ℓ_{av} = 2.34582 ≈ 2.35 cm. Calculate the relative error:

$$\varepsilon_X = \frac{\Delta l}{l_{av}} = \frac{0{,}03}{2{,}35} \approx 0{,}013.$$

The measurement result is written as:

$$l = (2{,}35 \pm 0{,}03)\,cm;\ \varepsilon_l = 0{,}013 = 1{,}3\,\%;\ (a = 0{,}95).$$

Let, when calculating the resistance of the conductor, we get the following result: R_{av} = 28.7673 ohms *and* ΔR = 2.4652 ohms.

First, we round off the absolute error, leaving one significant figure ΔR = 2.4652 Ohms ≈ 3 Ohms. Then we round the average value to the nearest integer R_{av} = *28.7673* Ohms ≈ 29 Ohms. We calculate the relative error:

$$\varepsilon_R = \frac{\Delta R}{R_{av}} = \frac{3}{29} \approx 0{,}11.$$

The measurement result is written as:

$$R = (29 \pm 3)\ \text{Ohms};\ \varepsilon_R = 0{,}11 = 11\,\%;\ (\alpha = 0{,}95).$$

From the above examples it can be seen that the absolute error is rounded up to the first significant figure upwards (with excess). The mean value of the measured quantity is rounded off with a correction to that significant digit, the digit of which coincides with the digit of the significant digit of the error. When rounding the relative error, we leave two significant figures.

An example of calculating the errors of direct measurements

Using a micrometer, the diameter of the ball is determined (the systematic measurement error is Δ = 0.005 mm).

1. We calculate the arithmetic mean of a series of *n* direct measurements:

$$X_{av}=\frac{1}{n}\sum_{i=1}^{n} X_i=\frac{2{,}45+2{,}43+2{,}37}{3}=2{,}42.$$

2. Calculate the absolute random error of each measurement ΔX_i is the difference between the arithmetic mean of a series of *n* direct measurements and the given measurement:

$$\Delta X_i = X_{av} - X_1 = 2.42 - 2.45 = -0.03,$$

$$\Delta X_2 = X_{av} - X_2 = 2.42 - 2.43 = -0.01;$$

$$\Delta X_3 = X_{av} - X_3 = 2.42 - 2.37 = 0.05$$

3. Calculate the mean square absolute error S_X.

$$S_X=\sqrt{\sum_{i=1}^{n} ¿¿¿¿}$$

4. Calculate the absolute random error ΔX_{random}: $\Delta X_{random} = t_{a,n} \cdot S_x$,

The Student's coefficient in this case is equal to: $t_{3.095} = 4.3$ (see Table 1.) Then we get $\Delta X_{random} = 4.3 \cdot 0.024 = 0.10$ mm.

5. Find the relative error:

$$\varepsilon_X=\frac{\Delta X}{X_{av}}\cdot 100\%=\frac{0{,}10}{2{,}42}\cdot 100\%=0{,}04\cdot 100\%=4\%.$$

6. Round off and write down the result: $d = (2.4 \pm 0.1)$ mm, with $\alpha = 0.95$.

Calculation of errors in indirect measurements

When calculating the error, it is necessary to take into account what the formula looks like, according to which the required physical quantity is calculated. The error for indirect measurements is calculated differently than for direct measurements.

For example, to find the value A, it was necessary to measure some values x , y , z . the value A is functionally related to the values x , y , z .

$$A = f(x, y, z).$$

With indirect measurements, the average absolute error $\Delta\bar{A}$ can be found by the rules of differentiation if the sign of the differential d replace with the error sign Δ and choose the signs in such a way that the error value is maximum, i.e.

$$dA=\frac{\partial A}{\partial x}dx+\frac{\partial A}{\partial y}dy+\frac{\partial A}{\partial z}\partial z(1)$$

and

$$\Delta\overline{A}=\frac{\partial A}{\partial x}\Delta\overline{x}+\frac{\partial A}{\partial y}\Delta\bar{y}+\frac{\partial A}{\partial z}\Delta\overline{z}(2)$$

If A is a function of one variable x , then

$$\Delta\overline{A}=\frac{dA}{dx}\Delta\overline{x}$$

those the absolute error of a function is equal to the absolute error of the argument multiplied by the derivative of this function with respect to this argument.

The relative error, as in direct measurements, is determined by the formula:

$$E=\frac{\Delta\bar{A}}{\bar{A}}\cdot 100\%$$

Considering that the differential of the natural logarithm

$$d(lnA)=\frac{dA}{A},$$

then

$$\Delta(ln\overline{A})=\frac{\Delta\bar{A}}{\bar{A}},(3)$$

or

$$E=\Delta(ln\overline{A})=\frac{\Delta\bar{A}}{\bar{A}}.(4)$$

So, the relative error of the result is equal to the total differential of the natural logarithm of the functions, which determines the dependence of this value on the measured values.

To determine the relative measurement error, the following algorithm is recommended:

1. Take the logarithm of the calculation formula,
2. Find the total differential from the logarithm,
3. Group all members containing the same differential (if there are such members), and take the expressions in brackets before the differential modulo.
4. Differential sign *d* replace with the error sign Δ.
5. Select the signs so that the relative error is maximum.

An example of calculating the errors of indirect measurements

Determine the absolute and relative errors from single measurements of the corresponding arguments of the coefficient η of the viscosity of castor oil, determined by the Stokes method.

The value of the viscosity coefficient η in this case is determined by the formula:

$$\eta=\frac{2r^2g(\rho-\rho_0)t}{9l},(5)$$

where *r is the* radius of the ball, *g is* the free fall acceleration, ρ - the density of lead, ρ_0 - the density of castor oil, *l* - the distance traveled by the ball, *t* - the time of the ball. As a result of the measurements, the following values were obtained:

l = 0.75 m, measured with an accuracy of 0.005 m, *r* = $2.0\cdot10^{-3}$ m, measured with an accuracy of $0.1\cdot10^{-3}$ m, *t* = 5.96 s, measured with an accuracy of 0.01 s,

$(\rho - \rho_0) = 1320$ kg / m^3, measured with an accuracy of 0.5 kg / m^3, g = 9.8 m / s^2, measured with an accuracy of 0.05 m/s^2.

1. Determine the viscosity coefficient η using expressions (5):

$\eta=2\cdot$¿¿

2. Taking the logarithm of expressions (5), we obtain:

$$\ln\eta = \ln 2+2\ln r+\ln g+\ln(p-p_0)+\ln t-\ln 9-\ln l$$

3. Differentiate the resulting expression:

$$\frac{d\eta}{\eta}=\frac{2dr}{r}+\frac{dg}{g}+\frac{dp}{p-p_0}-\frac{dp_0}{p-p_0}+\frac{dt}{t}-\frac{dl}{l}$$

4. We replace the sign of the differential with the sign of the increment and find the maximum relative error:

$$E=\frac{\Delta\eta}{\eta}=\frac{2\Delta r}{r}+\frac{\Delta g}{g}+\frac{\Delta p}{p-p_0}+\frac{\Delta t}{t}+\frac{\Delta l}{l}$$

Since $\Delta p_0 = \Delta p$, then

$$E=\frac{\Delta\eta}{\eta}=\frac{2\Delta r}{r}+\frac{\Delta g}{g}+\frac{\Delta p}{p-p_0}+\frac{\Delta t}{t}+\frac{\Delta l}{l}$$

Substituting numerical values we get:

$$E=\frac{\Delta\eta}{\eta}=\frac{2\cdot 0{,}01\cdot 10^{-3}}{2\cdot 10^{-3}}+\frac{0{,}05}{9{,}8}+\frac{2\cdot 0{,}5}{10320}+\frac{0{,}01}{5{,}96}+\frac{0{,}005}{0{,}75}=0{,}02$$

As a percentage, the relative error is:

$$E=\frac{\Delta\eta}{\eta}\cdot 100\%=0{,}02\cdot 100\%=2\%$$

The maximum possible absolute error in determining the viscosity is:

$$\Delta\eta = E \cdot \eta = 0.71 \cdot 0.02 = 0.014\ Pa{\cdot}s$$

The measurement result is presented as:

$$\eta = 0.710 \pm 0.014\ Pa{\cdot}s$$

Questions

1. What types of errors do you know? Describe them.
2. What is absolute error? Give definition and formula.
3. What is mean absolute error?
4. What is the relative error and how is it determined in the experiment?
5. What is the confidence interval of the measured value?
6. What are direct and indirect measurements?
7. What ways of defining a function do you know? Briefly describe each of them.

LAB WORK #1

DETERMINATION OF THE DENSITY OF BODIES OF REGULAR GEOMETRIC SHAPE

LAB №1

DETERMINATION OF THE DENSITY OF BODIES OF REGULAR GEOMETRIC SHAPE

The purpose of the work: familiarization with the instruments and measurement of linear quantities, instilling skills in processing results using the theory of errors.

Equipment: bodies of regular geometric shape, (parallelepiped, cylinder, ball) scales and weights, calipers, micrometer.

Theoretical introduction.

The density of a substance is a quantity measured by the mass of a substance contained in a unit volume. If the mass of a substance is m, and its volume is *V*, then the density of the body *ρ* is determined by the formula:

$$\rho=\frac{m}{V}.$$

In this work, we are dealing with bodies of regular shape. Their volumes are calculated according to known geometry formulas. Substituting the value of the volumes of the corresponding bodies into the density formula (1), we obtain the density formula for the substances of the corresponding bodies:

a) for a parallelepiped:

$$\rho=\frac{m}{V}=\frac{m}{abc},$$

where a is the length of the parallelepiped, b is its width, c is the height, m is the mass of the parallelepiped.

b) for a solid cylinder:

$$\rho=\frac{m}{V}=\frac{4m}{\pi d^2 h},$$

where *d* is the diameter of the cylinder, *h* is the height of the cylinder, *m* is its mass.

c) for a hollow cylinder:

$$\rho=\frac{m}{V}=\frac{4m}{\pi\left(D^2-d^2\right)h}$$

where *d* is the diameter of the ball, *m* is the mass of the ball.

г) for the ball:

$$\rho=\frac{m}{V}=\frac{6m}{\pi d^3},$$

где *d* – диаметр шара, *m* – масса шара.

The linear dimensions of bodies of the correct geometric shape are determined using a caliper or micrometer.

Description of devices

Calipers. To measure the linear dimensions of bodies with an accuracy of fractions of a millimeter, a caliper is used (Fig. 1).

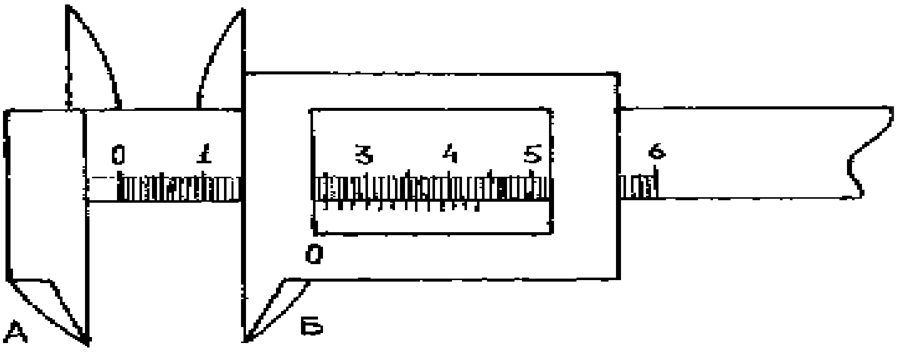


Fig.1 General view of the caliper.

The caliper is a device that has two scale rulers. On the fixed bar A there is a ruler divided into centimeters and millimeters. The second ruler is located on the movable part of the vernier (nonius) caliper, which is called the vernier Б. Usually the vernier scale has 10 divisions, which are equal to 9 divisions of the rod scale. Therefore, each division of the vernier is shorter than the division of the fixed scale by 0.1 *mm*. This number is called the vernier precision. In order to determine the price of the division of the vernier, it is necessary to combine the zero of the vernier with the zero division of the fixed bar scale and calculate how many divisions of the bar scale correspond to the divisions of the vernier.

If *n* divisions of the vernier correspond to *n-1* divisions of the barbell with the division price a, then $x\cdot n = a(n-1)$, from which it can be rewritten as a· x = $\frac{a}{n}$. The value $\frac{a}{n}$ is called the vernier precision.

Determining the size of the bodies is reduced to determining how far the zero of the vernier has shifted from the zero of the scale of the fixed bar. If the zero of the vernier caliper is set between the two risks of the ruler of the fixed rod (for example, between 5 and 6 *mm*, see Fig. 2), then using the vernier, you can determine a fraction of a millimeter. To do this, determine such a risk on the vernier scale, which coincides with the risk of a fixed millimeter ruler. Knowing the price of division of the vernier, we write the result in the table.

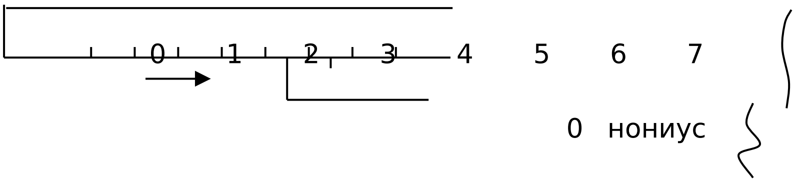


Fig.2. Determining the size of bodies using the vernier.

A micrometer is a device that allows you to measure the dimensions of bodies with higher accuracy. Fig. 3 shows a general view of the micrometer.

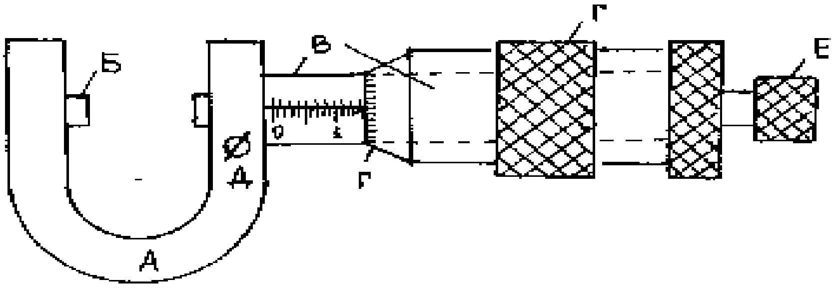


Fig. 3. General view of the micrometer.

Massive bracket *A* has a support foot *Б* at one end, and a cylindrical tube C with a thread inside, along which the screw moves, at the other. The screw thread pitch is 0.5*mm*. In other words, a screw turned by 360^0, i.e. for one complete revolution it moves progressively by 0.5 *mm*. If the screw is rotated 0.02 circles, then the translational displacement will be *0.01 mm*. The screw is connected to another, wider tube *Г*, which rotates and moves with the screw relative to the inner fixed tube *B*. 50 divisions of the scale are marked on the tube *Г*. Strokes of a fixed scale are marked along the inner fixed tube *B*. Using a movable scale and a stroke on the drum, you can determine the angle of rotation of the movable tube, and therefore the translational movement of the screw with an accuracy of *0.01 mm*. When the screw is brought into contact with the support heel B, then the zero division of the tube must coincide with the limit stroke 0 of the fixed tube C. If there is no match, then the indications are marked on the circular scale. This will be the statistical error of the instrument. It is taken with a plus or minus sign.

A ratchet is installed on the micrometer handle - an additional handle *E*, with which the screw should be rotated. When rotating, the ratchet emits a sound, which indicates the contact of the measuring surface with the body under study. The report on the micrometer is carried out as follows: to the integer number of millimeters protruding from under the cut of the circular scale, add the number of hundredths, which coincides with the line, and are counted on the circular scale of the drum. In the event that another division appears above the line of the fixed ruler after the counted whole millimeters protruding from under the cut of the circular scale, then another *0.5 mm* is added to the resulting number. Before counting, fix the position of the screw with a special stopper *D*.

Experiment order

1. Weigh the parallelepiped, cylinders on the scales.
2. Measure the height of the parallelepiped and the cylinder with a caliper.
3. Measure the width, length of the parallelepiped, diameter (internal and external) of the cylinder with a caliper. Each measurement is made three times in different places of the measured body.
4. Record the measurement results in tables (Tables 1–3).
5. Calculate the density of the parallelepiped and cylinders using formulas (3, 4, 5).
6. Relative errors are determined by the formulas:

a) for a parallelepiped: $$\frac{\Delta\rho}{\rho}=\frac{\Delta m}{m}+\frac{\Delta a}{a}+\frac{\Delta b}{b}+\frac{\Delta c}{c},$$

b) for a solid cylinder: $$\frac{\Delta\rho}{\rho}=\frac{\Delta m}{m}+\frac{\Delta h}{h}+\frac{2\Delta d}{d}+\frac{\Delta\pi}{\pi},$$

c) for a hollow cylinder: $$\frac{\Delta\rho_1}{\rho}=\frac{\Delta m}{m}+\frac{\Delta h}{h}+\frac{2\Delta d}{d}+\frac{2\Delta D}{D}+\frac{\Delta\pi}{\pi},$$

where $\Delta m = 0.1\ 10^{-3}$ kg, $\Delta\pi = 0.0016$.

Calculate the maximum possible absolute error:

$$\Delta\rho = E \cdot \rho$$

The measurement result is presented as:

$$\rho = \rho_{avg} \pm \Delta\rho$$

Table 1.

Hollow cylinder

№	m, kg	Δm, kg	h, m	Δh, m	D, m	ΔD, m	d, m	Δd, m	ρ, $\frac{kg}{m^3}$	$\Delta\rho$, $\frac{kg}{m^3}$	$\frac{\Delta\rho}{\rho}\cdot 100\%$
1											
2											
3											
Avg											

Table 2.

Solid cylinder

№	m, kg	Δm, kg	h, m	Δh, m	D, m	ΔD, m	d, m	Δd, m	ρ, $\frac{kg}{m^3}$	$\Delta\rho$, $\frac{kg}{m^3}$	$\frac{\Delta\rho}{\rho}\cdot 100\%$
1											
2											
3											
Avg											

Table 3

Parallelepiped

№	m, kg	Δm, kg	h, m	Δh, m	D, m	ΔD, m	d, m	Δd, m	ρ, $\frac{kg}{m^3}$	$\Delta\rho$, $\frac{kg}{m^3}$	$\frac{\Delta\rho}{\rho}\cdot 100\%$
1											
2											
3											
Avg											

Test questions

1. What is called the density of the body?

2. Derive the calculation formula for determining the density of the cylinder.
3. Which measurements in this work are direct, which are indirect?
4. Derive a formula for the relative error in measuring the density of a body in this work.
1.

LAB WORK # 3
DETERMINATION OF THE SPEED OF SOUND BY THE METHOD OF STANDING WAVES

Purpose of the work: measuring the speed of sound in air by the method of standing waves in a pipe, comparing the results of the experiment with theory.

Instruments and accessories : a glass cylinder connected by a rubber tube to a reservoir filled with water; sound generator (phone).

Brief theory

Sound - a physical phenomenon, which is the propagation in the form of elastic waves of mechanical vibrations of particles of a solid, liquid or gaseous medium. In a narrow sense, sound refers to vibrations in the context of how they are perceived by the sense organs of animals and humans. Sound is characterized by amplitude and frequency (frequency spectrum). Elastic waves propagating in the air, in which the frequency f of oscillations of air particles is in the range from 16 Hz to 20 kHz, reaching the human ear, causes a sensation of sound. In accordance with this, elastic waves in any medium, having a frequency that is within the specified limits, are also called *sound waves* or simply *sound*. Sound below the human hearing range is called **infrasound** ; higher: up to 1 GHz - by **ultrasound** , from 1 GHz - by **hypersound** . Usually, oscillating bodies of various nature are used to generate sound, causing periodic changes in the pressure of an elastic medium, for example, air. An example of such generation is vibrations of a loudspeaker diffuser, a tuning fork, vocal cords (vocal folds), and elements of most musical instruments. An exception are wind instruments, in which the sound is generated due to the interaction of the air flow with heterogeneities in the instrument. The field of physics that studies sound phenomena is called *acoustics* .

When a sound wave propagates in air at each point in space, compression and rarefaction deformations are observed alternately, which leads to a change in pressure in the medium compared to atmospheric (static) pressure. Variable value - the difference between atmospheric pressure and pressure at a given point in the environment is called *sound pressure* P_{sound} , which is sometimes called excess. The compression strain corresponds to a positive sound pressure value, and the rarefaction strain corresponds to a negative value. Sound pressure is a function of time and coordinates

$$P = P_{sound}(x, t).$$

Density is related to pressure and is also a variable

$$\rho = \rho_{sound}(x, t).$$

On fig. 1 shows pressure and density fluctuations in a sound wave.

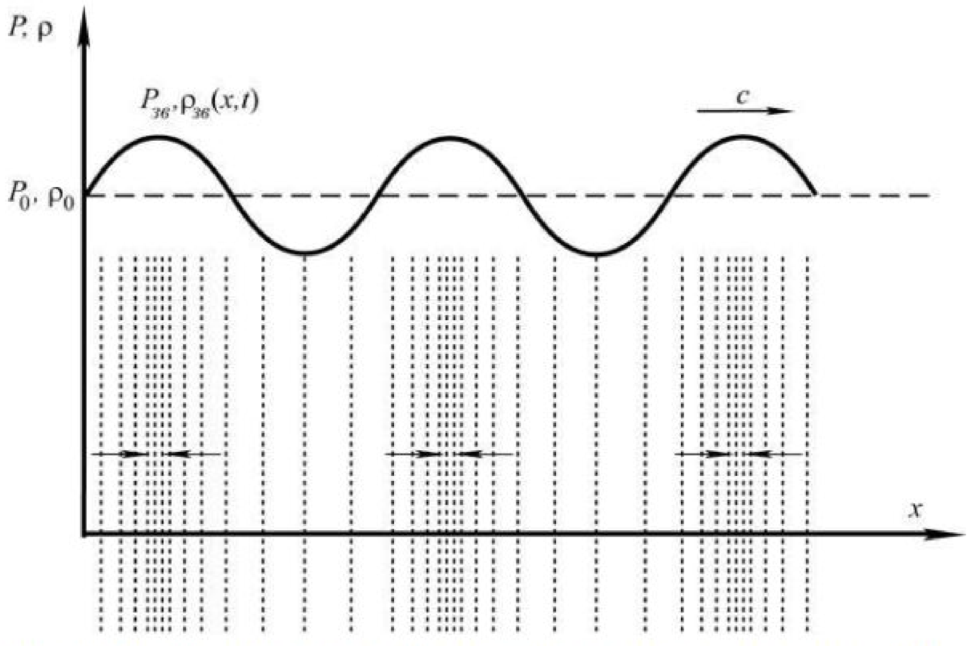


Fig.1

The distance over which a wave propagates in a time equal to the period of oscillation of the particles of the medium is called ***the wavelength***

$$\lambda = \upsilon T,$$

where υ is the speed of wave, T is the oscillation period.

The reciprocal of a period is called ***frequency .***

$$f = 1/T .$$

Taking this expression into account, we obtain the relation

$$\upsilon = \lambda f \qquad (1)$$

The speed of sound is a constant value for a given medium and depends on the propagation conditions. The velocity υ is inversely proportional to the square root of the elasticity coefficient of the medium α and its density ρ:

$$\upsilon=\sqrt{\frac{1}{\alpha\rho}}$$

Approximately this expression can be replaced by the following:

$$\upsilon=\sqrt{\frac{E}{\rho}},$$

where E is the Young's modulus of the medium.

The speed of sound can be determined experimentally by various methods. In this work, we use the measurement of the speed of sound in air by the method of standing waves.

Mathematically, the propagation of all types of waves is described by the wave equation. The wave equation is an expression that represents as a function of coordinates (*x, y, z*) and time *t* , characterizing the wave motion of an oscillating particle. Let us describe the form of the function ξ (*x, y, z, t*) in the case of a plane wave, assuming that the oscillations are harmonic in nature, and the *x axis* coincides with the direction of wave propagation. Then ξ (*x, t*).

The equation for a plane harmonic traveling wave propagating in the positive direction of the X axis is:

$$\xi = A\cos(\omega t - kx),$$

where A is the oscillation amplitude; ω – angular frequency: $\omega = 2\pi f$; k is the wavenumber: $k = 2\pi/\lambda$, ($\omega t - kx$) is the phase.

When two counter propagating plane waves with the same amplitudes are superimposed, ***standing waves are formed*** with characteristic points - nodes and antinodes of displacements. At certain points, called *antinodes* , the amplitude of the standing wave is equal to the sum of the amplitudes of both terms of the oscillations. At other points, the resulting amplitude is zero, these points are called *nodes of the* standing wave (Fig. 2).

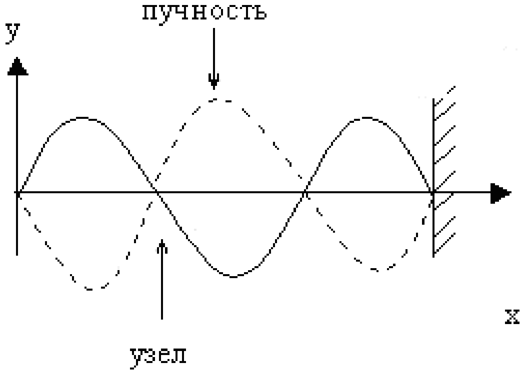


Fig.2

The standing wave equation can be obtained by adding the left and right sides of the two equations:

$$\xi_1 = A\cos(\omega t - kx);$$

$$\xi_2 = A\cos(\omega t + kx),$$

where ξ_1 is the displacement of the points of the straight line, and ξ_2 - backward or reflected from the obstacle wave. The following expression is obtained:

$$\xi = \xi_1 + \xi_2 = 2A\cos(2\pi/\lambda)x\cos\omega t.$$

This is how points in a standing wave move with time.

The factor cos ωt shows that oscillations of the same frequency occur at the points of the medium as the frequency of the counterpropagating waves.

The module of the multiplier $2A\cos(2\pi/\lambda)x$, which does not depend on time, is called *the amplitude of the resulting oscillation* , it depends on the coordinate of the point x .

At the points of formation of antinodes, the amplitude of the standing wave is equal to the sum of the amplitudes of both terms of the oscillations. The antinode coordinates can be found from the condition:

$$\left|\cos\frac{2\pi}{\lambda}x\right| = 1,$$

The antinode coordinates are the solutions of the last trigonometric equation:

$$x_n = \pm n\frac{\lambda}{2}; n = 0,1,2,\ldots$$

At the nodes, the amplitude of the resulting oscillation is always zero. Node formation condition:

$$\cos\frac{2\pi}{\lambda}x = 0,$$

from here you can find the coordinates of the nodes:

$$x_{nodes} = \pm(2n+1)\frac{\lambda}{4}.$$

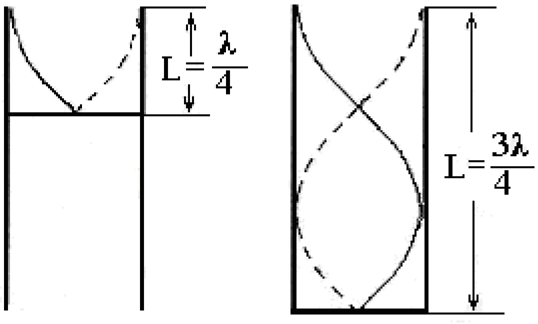
It is easy to show that the distances between two adjacent antinodes or nodes of a standing wave are equal to half the wavelength:

$$\Delta x = \frac{\lambda}{2},$$

the distance of the node from the nearest antinode is equal to λ/4.

These features make it possible to determine experimentally the wavelength, and then its speed. Standing waves are usually formed by the interference of direct and reflected waves.

Consider air vibrations in tubes. Let's place a sound generator over the upper open end of the tube and listen to the intensity of the sound. By increasing the water level in the tube, you can set it to a position where the sound intensity is particularly high. In this case, the sound waves emitted by the generator generate a standing wave inside the tube, so the sound waves are amplified by the reflected waves, and we hear an increase in sound intensity. The shortest air column at which this amplification occurs has a length L equal to ¼ of the sound wave length (Fig. 3a). If the piston is moved down, then a new intensity peak will be found when L = 3λ/4 (Fig. 3b). Essentially, standing waves are formed with this sequence of wavelengths: λ/4, 3λ/4, 5λ/4, etc.



a) б)

Fig.3.

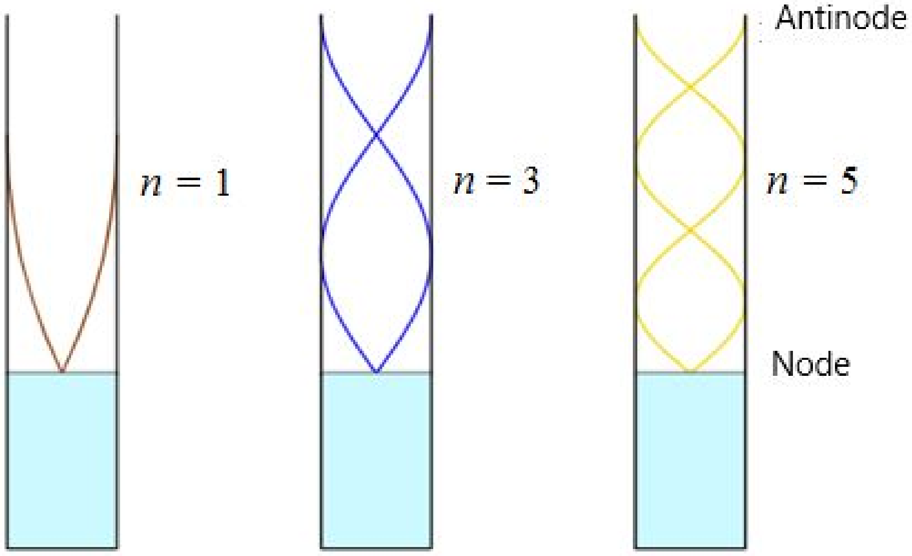
The described effect is a variation of the resonance phenomenon, in which there is an efficient transfer of energy from the sound generator to the air column in the tube, as a result of which the sound intensity increases. In reality, an air column in a tube closed at one end will resonate at the wavelengths of sound given by the sequence:

$$\lambda = 4L/n;\ n = 1, 3, 5 \ldots.$$

The frequencies corresponding to these wavelengths are:

$$\nu = \upsilon/\lambda = n\,\upsilon/4L;\ n = 1, 3, 5 \ldots.$$

If we designate the fundamental frequency ($n = 1$) as ν_1, then the sequence of frequencies of standing waves will be ν_1, $3\nu_1$, $5\nu_1$, etc. Thus, in an air column enclosed in a tube closed at one end, standing waves will occur only with frequencies corresponding to the odd harmonics of the fundamental frequency. This perfectly defined sequence of resonant frequencies is due to the fact that at one end (closed) of the tube there must be a node, and at the other (open) - an antinode (Fig. 3).



Installation description

The experimental setup consists of two communicating vessels: a glass cylinder (A) connected by a rubber tube to a storage tank (B) filled with water (Fig. 4) and a telephone (T). By raising the storage tank (B), you can change the water level in the cylinder (A) and thereby change the length of the air column. The position of the liquid level is measured on a scale. As a source of oscillations, a sound generator with a certain oscillation frequency *f*. The sound wave from the phone and the wave reflected from the water surface add up to form a standing wave in the air column above the water (Fig. 5). If the water level (distance x_1, or x_2, or x_3, etc.) is such that standing waves arise with a node on the surface of the water and an antinode at the open end of the vessel, then the intensity of sound traveling in space is maximum. When the

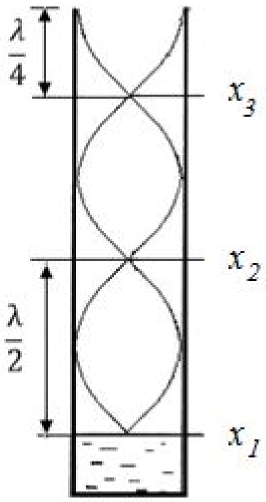


Рис. 5

water level in a cylindrical vessel rises, for example, from the level x_1, the sound is attenuated, and when the level x_2 is reached, it becomes stronger again, etc. Thus, the sound is amplified again when the water level moves a distance $\Delta x = x_2 - x_1 = \lambda/2$. In this case, an antinode is again formed at the upper end of the vessel, and a knot is formed on the surface of the water.

The length of the sound wave and the speed of sound are determined by the formulas:

$$\lambda = 2\,(x_2 - x_1) \quad (2)$$

$$\upsilon = \lambda f = 2\,(x_2 - x_1)\,f, \quad (3)$$

where x_1 is the position of the water level in the first case, x_2 is the position of the water in the second case ($x_2 > x_1$), f is the frequency of sound waves set by the generator.

Work order

1. Install the Sound Generator app on your phone.
2. Pour water into a glass cylindrical vessel (A).
3. Place the phone over the vessel (A). Turn on the sound generator and give a sound signal with a frequency of v = 1500 Hz.
4. Raising the storage tank (B) with water, increase the water level in the cylindrical vessel (A), determine the positions of the water level x_1 and x_2 at which the sound will be minimal.
5. Take measurements 3 times. Enter the measurement results in the table.
6. Carry out similar experiments with the frequency of sound waves f = 1700 Hz and 2000 Hz. Enter the measurement results in the table.
7. Calculate the length of the sound wave and the speed of sound using formulas (2-3).
8. Compare the obtained value of the speed of sound with the theoretical calculation from the expression

$$\upsilon = \upsilon_0 \sqrt{\frac{T}{273}},$$

where υ_0 is the speed of sound in air at 0°C, equal to 323 m/s,
T is the temperature of air in the Kelvins.

9. Calculate the relative error using the formula

$$E = \frac{\Delta \upsilon_{av}}{\upsilon_{av}} = \frac{2\Delta x}{x_2 - x_1} + \frac{\Delta v}{v},$$

where $\Delta x = 0.5\ 10^{-3}$ m, $\Delta \nu = 1$ Hz.

Table

No.	ν, Hz	x_1, m	x_2, m	λ, m	υ, m/s	$\Delta\upsilon$	$\frac{\Delta\upsilon_{av}}{\upsilon_{av}}\cdot 100\%$
1	1500						
2	1500						
3	1500						
Average							
1	1700						
2	1700						
3	1700						
Average							
1	2000						
2	2000						
3	2000						
Average							

Questions

1. What is a sound wave?
2. Write down the equation of a plane harmonic wave.
3. How are standing waves formed? What are nodes and antinodes of a standing wave? What is the distance between them?
4. How are wave propagation speed related to frequency and wavelength?
5. What determines the speed of sound in gases?
6. How the speed of sound depends on temperature.
7. What are the parameters of the sound wave associated with the volume of the sound?

LAB WORK # 4

DETERMINATION OF THE VISCOSITY COEFFICIENT OF A LIQUID ACCORDING TO THE STOKES METHOD

The purpose of the work: the study of the motion of bodies in a viscous fluid and the determination of the viscosity coefficient.

Required instruments and accessories *:* glass cylinders filled with glycerin and alcohol, lead balls, calipers.

Theoretical introduction

All real liquids and gases, to a greater or lesser extent, inherent ***internal friction*** , also called ***viscosity***. Viscosity has great importance in natural, especially biological processes, as well as in various fields of technology and in the study of hydrodynamic processes.

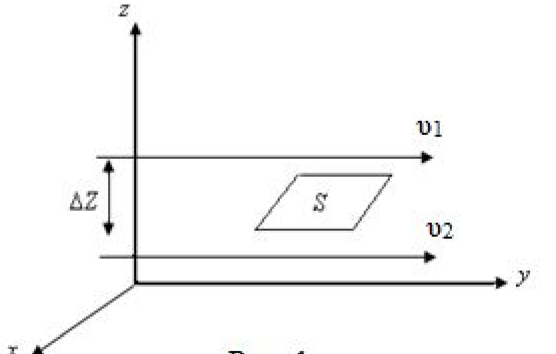


Рис. 1

The phenomenon of viscosity in liquids and gases can be considered as follows. Let us assume that there are two liquid layers moving parallel to each other with different speeds υ_1 and υ_2 at a distance Δz (Fig. 1). When moving some fluid layers relative to others, internal friction forces arise, directed tangentially to the surface of the layers. The action of these forces is manifested in the fact that from the side of the layer moving faster, the layer moving more slowly is affected by an accelerating force. From the side of the layer moving more slowly, the layer moving faster is affected by a retarding force.

Let at some moment of time the layers have momenta $m\upsilon_1$ and $m\upsilon_2$. Due to thermal motion, there is a continuous transition of molecules from one layer to another. Once in another layer, the molecule undergoes collisions with the molecules of this layer, as a result of which it either gives up an excess of its momentum to other molecules (if it arrived from a layer moving faster), or increases its momentum due to other molecules (if it “arrived” from layer moving slower). As a result, the momentum of the layer moving faster decreases, and the layer moving more slowly increases. Consequently, the layers behave as if a force slowing down its movement was applied to the layer, the speed of which is greater, and a force of the same magnitude accelerating its movement was applied to the layer, the speed of which is lower. So, the reason for the appearance of viscosity (internal friction) is the transfer of momentum from one layer to another. It has been experimentally established that the modulus of the internal friction force applied to the area S , lying on the boundary between the layers, is determined by the formula

$$F=\eta\frac{d\upsilon}{dz}A \tag{1}$$

where A is the area of contact between the layers, on which the force F *acts* ;

$\frac{d\upsilon}{dz}$ - change in speed, shows how quickly the speed changes when moving from layer to layer in the direction z, perpendicular to the direction of movement of the layers, and is called *the velocity gradient* ;

η is the dynamic viscosity (viscosity) of the liquid (gas). Viscosity is measured in pascal seconds (Pa•s).

For liquids whose flow obeys equation (1), the viscosity does not depend on the velocity gradient, such liquids are called **Newtonian** , and the viscosity is **normal** . Liquids consisting of complex and large molecules (for example, polymer solutions) do not obey Newton's equation (1) and are called **non-Newtonian** , and the viscosity is **anomalous.** The non-Newtonian fluid is blood, because contains proteins and blood cells.

The viscosity of a liquid is greatly influenced by its composition. The viscosity of human blood normally ranges from 4 to 5 mPa ·s, while in pathology it can vary from 1.7 to 22.9 mPa ·s. It depends on the concentration of its components: water, mineral salts, proteins, etc. Therefore, blood viscosity has a diagnostic value. In some infectious diseases, blood viscosity increases, and in tuberculosis it decreases. Viscosity depends on the nature of the liquid, on temperature.

With increasing temperature, the viscosity of liquids decreases, because. the interaction between molecules decreases, the mobility of molecules increases, the time of "sedentary life" of molecules, called the relaxation time, decreases.

Viscosity is manifested in the movement of not only liquid through the vessels and bodies in the liquid. At low speeds, in accordance with Newton's equation, the resistance force to a moving body is proportional to the viscosity of the fluid, the speed of the body, and depends on the shape and size of the body.

The simplest body shape is a sphere. For a spherical body (ball), the dependence of the resistance force when it moves in a vessel with a liquid is expressed by the Stokes formula (law).

$$F_d = 6\pi\eta r\upsilon, \quad (2)$$

where r is the ball radius; υ - the speed of its movement, η - the coefficient of dynamic viscosity.

The experimental setup consists of a glass vessel A filled with the investigated liquid (Fig. 2). Three forces act on a moving ball in a liquid :

1) gravity of the ball $P = mg$ directed vertically down;

2) pushing out force (Archimedes force) F_A directed upwards,

3) friction force (resistance) F_{fr} (F_r) - directed upwards (Fig. 2). The emergence of this force is not due to the friction of the ball on the liquid, but is associated with the movement of the liquid itself. The layers of liquid entrained by the ball move along with it, the speed of these layers decreases with distance. The presence of a velocity gradient causes the appearance of internal friction forces between the layers of the liquid.

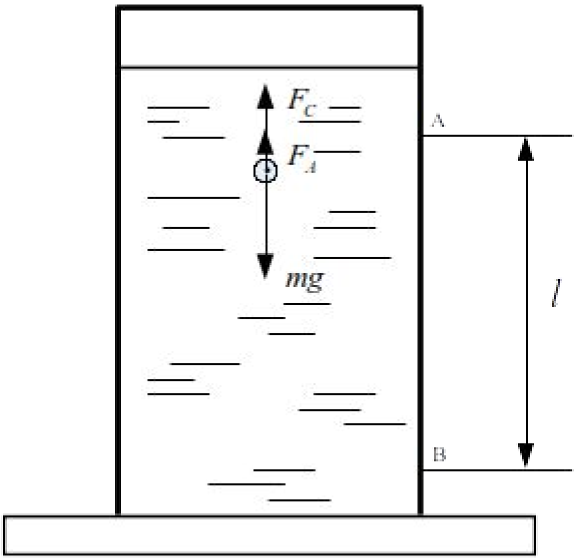


Рис.2

The force of gravity P and the buoyancy force $F_{pushing\ out}$ are determined through the volume of the ball:

$$P = mg = \rho V g = \rho \frac{4}{3}\pi r^3 g \quad (3)$$

$$F_p = \rho_1 \frac{4}{3}\pi r^3 g \quad (4)$$

ρ is the density of the ball and ρ_1 is the density of the liquid.

Gravity and buoyancy are constant, while drag is directly proportional to speed. When a ball moves in a liquid, there comes a moment when all three forces are balanced:

$$\vec{P}+\vec{F}_p+\vec{F}_r=0$$

and the ball starts moving uniformly, or in scalar form

$P = F_{pushing\ out} + resistance_t$, or $\frac{4}{3}\pi\rho r^3 g=\frac{4}{3}\pi\rho_1 r^3 g+6\pi r\eta\upsilon$

Where

$$\eta=\frac{2}{9}r^2 g\left(\frac{\rho-\rho_0}{\upsilon}\right) \qquad (5)$$

where ρ is the density of the ball (11350 kg/m3) ;
ρ_0 is the density of the liquid (glycerin - 1260 kg / m ^{3} ,
technical alcohol 796 kg / m ^{3});
V is the volume of the ball; m is the mass of the ball; g =9.8 m / s ^{2} - free fall acceleration; r is the radius of the ball.

Since the radius $r = d/2$, formula (5) takes the form

$$\eta=\frac{d^2 g(\rho-\rho_1)}{18\upsilon} \qquad (6)$$

In this work, the viscosity coefficient of glycerin and technical alcohol poured into a glass cylinder is measured (Fig. 2). The walls of the cylinder are labeled *A* and *B*. The speed of the ball can be determined by knowing the distance *l* between the marks on the vessel and the time *t* during which the ball travels this distance. The upper mark *A* must be at such a distance from the level of the liquid under study that the ball has time to acquire a constant speed by the time the mark passes. The lower mark *B* is applied for the convenience of timing.

Work order

1. Measure the diameter of the ball (*d*) with a caliper.
2. Measure the distance between the two marks (*l*).
3. Dip the balloon into the glycerin cylinder.

4. Determine with a stopwatch the time it takes for the ball to travel the distance between the marks. *A* and *B*.
5. Repeat the experiment 3 times with different balls .
6. Calculate the speed of the ball $\upsilon = l/t$.
7. Calculate the viscosity coefficient according to the formula (6) for each ball, find its average value and error.
8. Repeat steps 1 - 8 for the industrial alcohol cylinder.
9. Record the results of measurements and calculations in Table 2.
10. In the report, indicate the temperature at which the viscosity coefficient was measured and analyze the results.
11. Calculate the relative measurement error using the formula (7)

$$E=\frac{\Delta\eta_{av}}{\eta_{av}}=2\frac{\Delta r_{av}}{r_{av}}+\frac{\Delta g}{g}+\frac{2\Delta\rho_{av}}{\rho_{av}-\rho_{0av}}+\frac{\Delta t_{av}}{t_{av}}+\frac{\Delta l_{av}}{l_{av}}, \quad (7)$$

where $\Delta r = 0.01\ 10^{-3}$ m, $\Delta g = 0.005$ m / s^2, $\Delta\rho = 0.5$ kg / m^3, $\Delta t = 0.01$ s,
$\Delta l = 0.005$ m.

As a percentage, the relative error is:

$$E=\frac{\Delta\eta_{av}}{\eta_{av}}\cdot 100\%$$

12. Calculate Absolute Error from Known Relative Error $\Delta\eta_{av}=\eta_{av}E$
13. Record the results of measurements and calculations in a table.
14. Write the final measurement result as:

$$\eta=\eta_{av}\pm\Delta\eta_{av}$$

Table 1. *Viscosity of glycerin*

No.	*d* , m	Δd	*l,* m	*t, s*	Δt	υ, m/s	Δυ	Δη, Pa s	Δη	$\frac{\Delta\eta_{av}}{\eta_{av}}\cdot 100\%$
1										
2										
3										
Average										

Table 2. *Alcohol viscosity*

No.	*d*, m	Δd	*l*, m	*t, s*	Δt	υ, m/s	Δυ	Δη, Pa s	Δη	$\frac{\Delta\eta_{av}}{\eta_{av}}\cdot 100\%$
1										
2										
3										
Average										

Questions

1. Define viscosity.
2. Write Newton's equation for a viscous fluid.
3. How does the viscosity of a liquid depend on temperature?
4. What are Newtonian and non-Newtonian fluids? Explain why blood is a non-Newtonian fluid.
5. In what units is the viscosity measured in the system US?
6. What forces act on the ball as it moves through the fluid, and what is the nature of these forces?
7. What is the essence of the Stokes method? Derivation of the calculation formula for determining the viscosity of liquids.

LAB WORK_# 5

DETERMINATION OF THE COEFFICIENT OF THE SURFACE TENSION OF WATER BY THE METHOD OF DROP SEPARATION

Purpose of the work: study phenomena superficial tension; experimental determination of the coefficient of surface tension water method separation drops.

Instruments and accessories: syringe for clean water, syringe for soap solution (5-10 ml volume), cup of clean water, cup of soap solution, caliper or micrometer, sharpened pencil.

Theoretical introduction

Surface tension is a phenomenon in which a substance (primarily a liquid) tends to acquire a shape with the smallest possible surface area. This is achieved due to the presence of surface tension forces. Approximation to a spherical shape is achieved the more, the weaker the gravity. But even with normal gravity, small amounts of liquid media tend to take on a spherical shape corresponding to the smallest surface area, since in small drops the surface tension force significantly exceeds the force of gravity.

The liquid state of a substance is characterized by a much smaller distance between molecules than in a gas, more significant forces of attraction between molecules, and very significant repulsive forces that appear during volume compression. The molecular motion of fluid particles is basically an oscillatory motion around a mean position. Translational motion is limited by the exchange of places with neighboring particles.

Strictly speaking, any body is not in a vacuum, but in some other medium, for example, in the atmosphere. Therefore, should speak not just about the surface of bodies, but **about the interfaces between two medum**.

At the interfaces of a liquid and its saturated vapor, two immiscible liquids, a liquid and a solid, forces arise due to various intermolecular interactions of the adjacent media: primarily hydrogen bonds and weaker nonpolar interactions.

Molecules inside the liquid are surrounded on all sides by the same molecules (Fig. 1b), so the attractive forces from the neighbors are compensated. The vector sum of attractive forces from the neighbors is equal to zero - the molecule is in equilibrium. Molecules located near the surface in a certain thin surface layer (Fig. 1a) are in conditions different from those inside the body: molecules near the surface have the same neighbors with them only on three sides. Therefore, the attractive forces from the neighbors are not compensated, which means that it is affected by an uncompensated force directed inside the liquid. Because of this, the molecule tends to go there, in depth. In this case, the surface of the liquid tends to decrease.

This leads to the fact that the energy of molecules in the surface layer is different from their energy inside the body. The difference between the energy of all molecules near the interface and the energy that these molecules would have if they were inside the body is called the surface energy.

Fig.1.

Scheme of interaction of molecules with their neighbors:

a - a molecule located near the surface in a certain thin surface layer interacts with the same molecules only from three sides;

b - a molecule inside the liquid is surrounded on all sides by the same molecules.

Surface energy is the excess energy of the surface layer at the phase boundary (compared to the energy of the substance inside the body), due to the difference in intermolecular interactions in both substances.

It is obvious that the surface energy E_{sur} is proportional to the area A of the interface:

$$E_{sur} = \sigma A,$$

where σ is the surface tension coefficient, which depends on the nature of the media in contact and on their state.

Surface energy E_{sur} tends to take the smallest possible value. It follows from this that the interface between two media always tends to decrease. It is precisely with this that the tendency of liquid droplets (or gas bubbles) to take on a spherical shape is connected: for a given volume, the ball has the smallest surface of all figures. This tendency is counteracted by the influence of gravity, but for small droplets this influence is weak and their shape is close to spherical.

In this case, the molecules of the surface layer are drawn into the liquid. To move molecules from a liquid to its surface, it is required to do work W, equal in modulus to the surface energy, i.e.

$$W = E_{sur} = \sigma A.$$

From this follows the definition of the coefficient of surface tension.

The coefficient of surface tension (surface tension) σ is equal to the work W required to form a surface of a liquid with an area A at a constant temperature:

$$\sigma = \frac{W}{A}$$

Surface tension can be determined not only energetically. Surface tension manifests itself as a force in the following simple example. Let us imagine a liquid film (for example, a soap film) stretched over a square wire frame, each side of which has length L. Due to the tendency of the surface to decrease, a force will act on the wire, which can be directly measured. At a constant force F *, the* work is equal to

$$W = FL .$$

Then:

$$\sigma = \frac{W}{A} = \frac{FL}{\text{¿}} = \frac{F}{L}$$

So, on the line that bounds the surface of the body (or any part of this surface), forces act perpendicular to this line tangentially to the surface, inside it. The surface layer of a liquid is always limited by the line of possible rupture and is under the action of surface tension forces in constant tension, which tends to reduce the surface. Reduction of the surface is possible provided that the surface tension forces are tangential to the surface and perpendicular to the line of possible rupture.

This implies *the second definition* : the surface tension coefficient σ is equal to the surface tension force Facting *per* unit length L of the segment on which this force acts (lines of possible rupture):

$$\sigma = \frac{F}{L}$$

The dimension of σ follows from its definition and can be represented in various forms: energy per unit area (J/m^2) or force per unit length (N/m). Dimensional analysis shows the equivalence of these units:

$J / m^2 = N \cdot m / m^2 = N / m.$

When specifying the value of the surface tension coefficient, it is necessary to indicate which two media are in contact. Simply the surface tension of a liquid (without specifying the second medium) is often called the surface tension at the boundary of a given liquid and its vapor. This value decreases linearly with increasing temperature.

The surface tension forces do not change in any way as the surface area of the film decreases, since the density of the liquid, and, consequently, the average distance between molecules on the surface does not change.

Below are the values of surface tension for some liquids at a temperature of 20 °C (Table 1).

Table 1.

The value of the surface tension coefficient σ (in mN/m) for some liquids at a temperature of 20 °C (the second phase is air)

Liquid	**σ, mN/m**	**Liquid**	**σ, mN/m**
Water	72.5	Ether	17.0
Bile	48.0	Benzene	29.0
Milk	50.0	Mercury	465.0
Alcohol	22.0	Gold (1130 °C)	1100.0

The minimum surface tension of liquid helium at its border with its vapor is only 3.5 mN/m (near absolute zero). For most substances, the surface tension ranges from 10 to 2000 mN/m. Biological cell membranes have $\sigma = 100$ mN/m.

The value of surface tension has a diagnostic value in the clinic. Usually, the surface tension of biological fluids is compared with water - 72.5 mN/m at room temperature.

For example, normally, the value of σ *in* human blood plasma, serum, and urine is 72, 56, and 70 mN/m, respectively. This means that the surface tension of urine and blood plasma is close to water, and serum is less than that of water.

The appearance of bile pigments in the urine leads to a sharp decrease in σ from 70 to 56 mN/m.

Substances dissolved in a liquid are capable of both lowering and slightly increasing the surface tension. Solutes that lower the surface tension of a liquid are called ***surface-active substances*** (surfactants). They reduce the energy of the surface layer. Examples of surfactants in everyday life are soap and washing powders.

The total amount of a substance that can generally be fixed (adsorbed) on the surface of a liquid is very small. Therefore, even negligible surfactant impurities, accumulating on the surface of a liquid, can significantly change its surface tension. The surface tension of a liquid is very sensitive to its purity. So, small additions of soap can reduce the surface tension of water by more than 3 times.

In the treatment of various diseases, most liquid preparations are recommended to be taken by prescription in a certain number of drops. These droplets are formed by the slow flow of liquid from a small hole, the shape of the drop being determined by the forces of surface tension and gravity.

The surface tension of biological fluids in some cases can serve as a diagnostic factor. So, for example, with jaundice, the surface tension of urine decreases sharply due to the appearance of bile acids in the urine. In diabetes and some other diseases, the content of lipase in the blood increases. The content of lipase is judged by the change in the surface tension of the tributylene solution when blood is added to it.

To determine the surface tension coefficient, there are several methods: capillary, droplet separation (stalagmometric), ring separation method, Rebinder method.

In this paper, the droplet separation method is used to determine the surface tension coefficient.

Droplet separation method. The drop detachment method is based on the fact that when liquid drops are formed, flowing from a narrow vertically located tube of inner radius r, the drop detachment occurs at the moment when its gravity force F_{gr} overcomes the surface tension force $F_{surg\ tengsion}$ the perimeter of the drop neck (Fig. 2a).

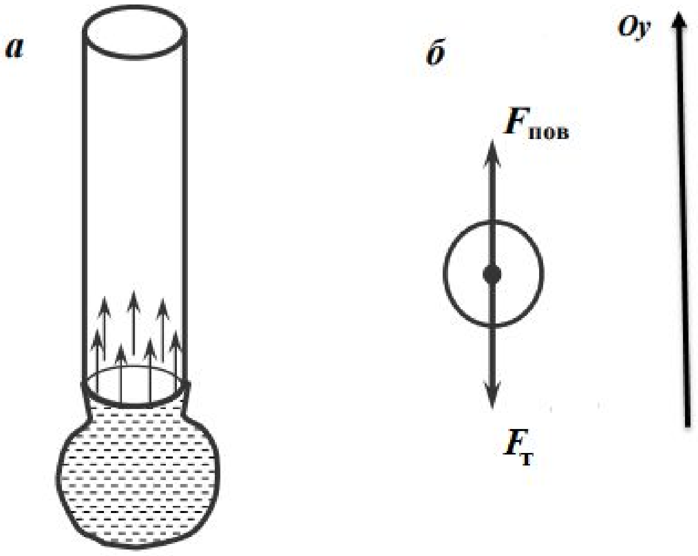


Fig. 2. Method of detachment of a drop from the tip of a capillary: a – along the circumference of the neck of the capillary, the force of surface tension acts (indicated in the form of thin arrows);
b – at the moment of drop detachment, an unstable equilibrium is observed.

We consider the radius of the drop neck to be equal to the inner radius r of the tube. At the moment of detachment, an unstable equilibrium is observed, i.e., the sum of all forces acting on the drop is equal to zero. Since there are only two forces, then modulo $\boldsymbol{F}_{gr} = \boldsymbol{F}_{surg\ tension}$ (Fig. 2b). By definition of the surface tension coefficient

$$\sigma = \frac{F}{l}$$

where l is the length of the surface of the drop in contact with the tube and is equal to the circumference $l = 2\pi r = \pi d$, and hence

$$F_{surg\ tension} = \sigma l = \pi d \sigma.$$

The force of gravity is

$$F_{gr} = mg,$$

where g is the free fall acceleration, m is the mass of the drop.

$$\pi d \sigma = mg.$$

From here

$$\sigma = \frac{mg}{\pi d} (1)$$

Work order

1. Measure the inner diameter *d* of the syringe tip. You can use a sharpened pencil to measure. Pushing the pencil into the tip until it stops, mark the border of contact between the tip and the pencil. The diameter of the pencil at the level of this boundary can be taken as the inner diameter of the tip and measured with a caliper or micrometer.
2. Fill the syringe M = 4 - 5 ml of water and, holding it vertically and gently pressing the piston, pour it into a glass, counting the drops. Measure the number of drops *N* at least three times.
3. For each *N* calculate mass one drops: $m = M/N$.
4. Record the measurement results in a table.
5. Using formula (1), calculate the coefficient of surface tension of water σ.
6. Similarly, determine the surface tension coefficient of the soap solution (use a separate syringe and utensils!)
7. Calculate the relative measurement error using the formula (2)

$$E = \frac{\Delta\sigma_{av}}{\sigma_{av}} = \frac{\Delta m_{av}}{m_{av}} + \frac{\Delta g}{g} + \frac{\Delta\pi}{\pi} + \frac{\Delta d_{av}}{d_{av}} , (2)$$

where $\Delta g = 0.005$ m / s ^{2} , $\Delta\pi = 0.0016$, $\Delta d = 0.2\ 10^{-3}$ m.

8. Calculate Absolute Error from known relative error $\Delta\sigma_{av} = \sigma_{av} E$
9. Record the results of measurements and calculations in a table.
10. Write the final measurement result as: $\sigma = \sigma_{av} \pm \Delta\sigma_{av}$

Table 2 .

Determination of the coefficient of surface tension of water

No.	*M, g*	ΔM	*N*	*t, g*	Δt	*d* , mm	σ, N/m	Δσ	$\frac{\Delta\sigma_{av}}{\sigma_{av}}$
1									
2									
3									
Average									

Table 3

Determination of the surface tension coefficient of a soap solution

No.	*M, g*	ΔM	*N*	*t, g*	Δt	*d* , mm	σ, N/m	$\Delta\sigma$	$\frac{\Delta\sigma_{av}}{\sigma_{av}}$
1									
2									
3									
Average									

Questions

1. Why do aqueous solutions of surfactants always have a lower surface tension than pure water?
2. Describe the mechanism of surface tension in liquids
3. Give the definition of surface tension coefficient . Get its dimension.
4. Where do surface tension forces originate? Qualitatively explain their occurrence. How are they directed?
5. On what factors does the coefficient of surface tension?
6. Tell us about the method for determining the coefficient of surface tension in given work.

LAB WORK # 8

DETERMINING THE WAVELENGTH OF LASER RADIATION USING A DIFFRACTION GRATING

***Purpose of the work*:** study of the diffraction of monochromatic laser radiation on a diffraction grating, determination of the wavelengths of laser radiation.

Instruments and accessories: laser, optical bench, diffraction grating, ruler, screen.

BRIEF THEORETICAL PART

Diffraction is a phenomenon of deviation of light rays from rectilinear propagation when light waves pass near opaque obstacles and sharp inhomogeneities. This phenomenon is characteristic of any wave process. Light diffraction is practically observed if the dimensions of the obstacles or holes are of the same order of magnitude as the wavelength of light, or if the place of observation of diffraction is at a large distance from the obstacles of final dimensions. During diffraction in the region of the geometric shadow, the illumination is redistributed and maxima and minima of light are observed. The phenomenon of diffraction is observed for plane and spherical waves. The phenomenon of plane wave diffraction is considered below. To explain the phenomenon, consider a parallel beam of rays incident on an opaque screen with holes (Fig. 1).

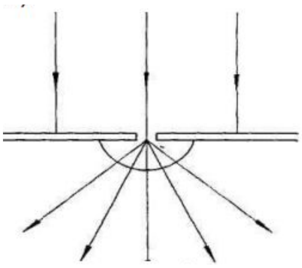


Fig.1

Before the screen, the wave front is a plane. According to the Huygens principle, each point of the wave front can be considered as a secondary independent source of spherical waves. Consequently, a beam of not parallel, but divergent rays appears behind the screen.

The diffraction grating is a regularly alternating transparent and opaque bands, the transverse dimensions of which are comparable to the wavelength of light. Usually, gratings are glass plates, on which parallel identical strokes are applied using a special machine, located at exactly the same distances from each other. The number of strokes is brought up to several thousand per 1 mm. ***The period*** or ***constant of***

a diffraction grating is the sum of the widths of a transparent and opaque gap: **a + b = d.**

Let a monochromatic beam of parallel rays fall on the grating perpendicular to its surface. The wave front is parallel to the grating plane. Each grating slit behaves like a point source of secondary coherent waves. After the grating, the rays go in all directions, therefore the angles of deviation of the rays from the original direction have values from 0° to 90° to the right and left. If a converging lens is placed behind the grating, then a diffraction pattern can be observed in the focal plane of the lens, which is the result of two processes: diffraction of light from each slit and multipath interference of light from all slits. The resulting picture, observed on screen E, consists of a set of minima (extinguishing of rays during interference) and maxima (amplification of light fluxes during interference), different in intensity. The maxima that are formed as a result of the interference of rays deviated by the same angle from different slots, and the path difference of which is a multiple of the wavelength, are called ***principal*** . Figure 2 schematically shows the path of rays through a diffraction grating into a lens.

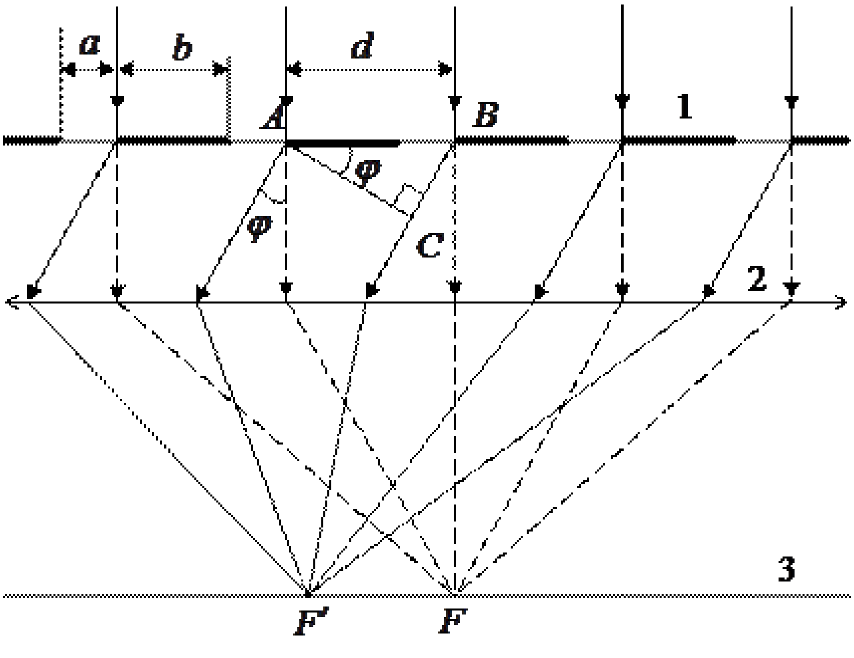


Fig. 2. Path of rays in a diffraction grating.

1-diffraction grating; 2 - lens; 3 - screen; *a* is the width of slit, b is the width of stroke, d is the grating period (AB), φ is the diffraction angle.

The path difference (Δ) between the waves from the edges of adjacent slots is equal to segment AC. The lens focuses waves traveling at an angle α $\varphi$to one point (F') on the focal plane, where they add, reinforce or attenuate each other. From drawing

$$AC = AB \cdot \sin \varphi,\ AB\cdot \sin \varphi = d\ \ \sin \varphi.$$

The maxima will be observed at an angle determined by the condition:

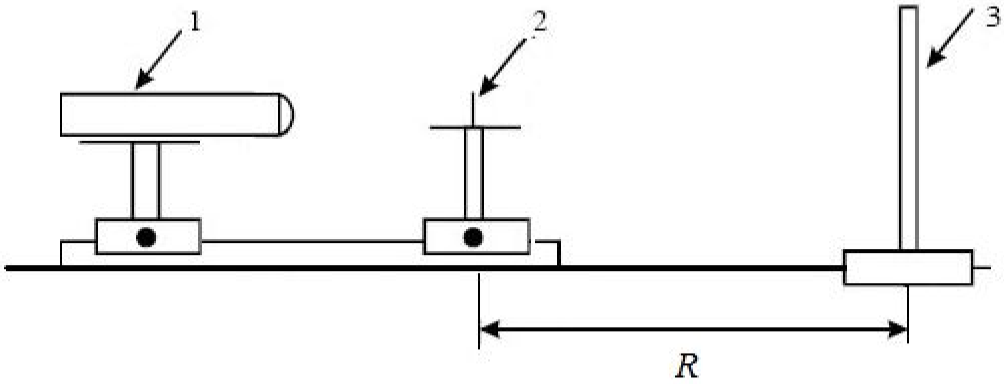
$d \sin \varphi = k\,\lambda,$ where k = 0,1,2 ... is the order of the maximum (1)

In the direction of undeflected waves ($\varphi = 0$, $k = 0$), a zero maximum is observed, which is the center of the diffraction pattern. For k = 1, there will be first-order maxima on both sides of the zero maximum; for k = 2, second-order maxima, and so on. The diffraction pattern is a system of alternating light and dark bands arranged symmetrically to the zero maximum. When the diffraction grating is illuminated with non-monochromatic light (for example, white), in the focal plane of the lens, instead of light bands, spectra separated by dark gaps will be visible.

Thus, knowing the grating period d, the order of maximum k, and the diffraction angle φ, one can find the light wavelength λ.

Work order

1. Install a diffraction grating and a ruler screen on the optical bench perpendicular to the laser axis (Fig. 3).
2. Turn on the laser.



Gig. 3. Installation for observations of the diffraction of laser beams on a diffraction grating.

1 - laser; 2 - diffraction grating; 3 - screen; R is the distance between the grate and the faucet.

3. Set the screen so that the laser beam, passing through the diffraction grating, forms a zero-order maximum at the zero mark of the scale.

4. Measure the distance x_1 from the middle of the main high to the middle of the first. In the same way, measure the position of the second, third and fourth peaks (Fig. 4).

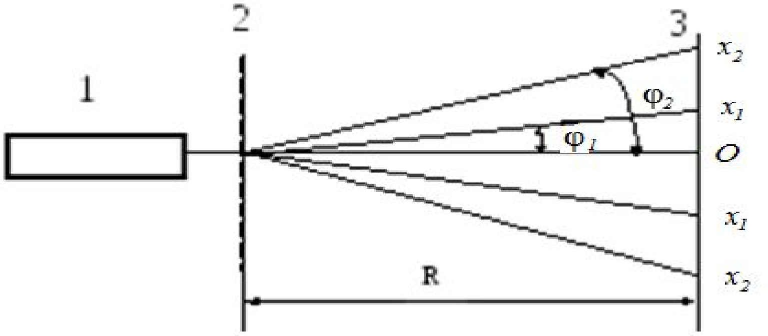
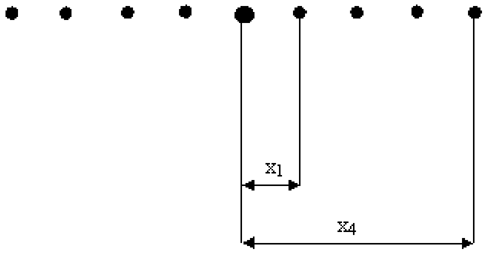


Fig. 4. Scheme of formation of the diffraction pattern
1 - laser; 2 - diffraction grating; 3 - screen; R is the distance between the grating and the screen; O is the position of the main maximum of the zero order; *x* is the distance between the chosen maximum and the maximum of zero order; φ is the diffraction angle for the selected maximum.

5. Turn off the laser.



6. Measure the distance *R* from the laser to the screen.
7. Calculate the wavelength of light using the formula

$$d\ sin\varphi = k\ \lambda\ ,$$

where *d* is the period of the diffraction grating (1/100 mm); because corners are small

$$\sin\varphi \approx \mathrm{tg}\,\varphi\ , \quad \sin\varphi \approx \frac{x}{R}.$$

8. Calculate Relative Error

$$E=\frac{\Delta\lambda_{av}}{\lambda_{av}}=\frac{\Delta d}{d}+\frac{\Delta x}{x}+\frac{\Delta R}{R},$$

where $\Delta d = 0.5\ 10^{-5}$ m, $\Delta x = 0.5\ 10^{-3}$ m, $\Delta R = 0.5\ 10^{-3}$ m.

As a percentage, the relative error is:

$$\varepsilon=\frac{\Delta\lambda_{av}}{\lambda_{av}}\cdot 100\,\%$$

9. Maximum absolute error $\Delta\lambda_{av}=\lambda_{av}E$

10. Write the final measurement result as:

$$\lambda=\lambda_{av}\mp\Delta\lambda_{av}$$

11. Replace the first laser with a different color laser and take the same measurements.

	First laser							Second laser						
No.	R, m	x, m	k	sin φ	λ, m	Δ λ, m	E, %	R, m	x, m	k	sin φ	λ, m	Δ λ,m	E, %
1														
2														
3														
4														
Av														

Questions

1. What is the phenomenon of diffraction?
2. What is a diffraction grating? Characteristics of the diffraction grating.
3. What properties of light are confirmed by the diffraction of light?
4. Under what conditions is light diffraction observed?
5. Why are the maxima located both to the left and to the right of the zero maximum?

PHYSICAL WORKSHOP
RADIOACTIVE RADIATION

***The purpose of the work** :* Studying the patterns of radioactive decays and the occurrence of radioactive radiation, their interaction with substances and familiarization with the dosimetry of ionizing radiation.

Brief theoretical information

1. Radioactivity

The nucleus of an atom is a quantum mechanical system consisting of nucleons: protons and neutrons. The nucleons in the nucleus are interconnected by the so-called nuclear forces.

The property of the nuclei of certain elements to spontaneously transform into the nuclei of other elements with the emission of radioactive radiation is called **radioactivity.** The phenomenon itself is called **radioactive decay.**

***Radioactivity* is** the spontaneous transformation of the nuclei of one element into another, in which the nucleus passes into a more stable state. The process is accompanied by the emission of ionizing radiation (corpuscular or electromagnetic).

Radioactive transformations are characterized by:

1) a method for isolating excess energies, which is given off either in the form of alpha or beta particles of a certain energy, or electromagnetic radiation;
2) the time of radioactive decay and the probability of nuclear decay per unit time. Radioactive decay is a statistical phenomenon. It is impossible to predict exactly when a given unstable nucleus will decay. To describe the statistical regularities of radioactive decay, a natural statistical value is used, called the decay constant λ, it does not depend on time. The meaning of the value of λ is that if we take a large number *N of* identical unstable nuclei*,* then λN nuclei will decay on average per unit time . The value of λN is called activity and characterizes the radiation of the preparation as a whole, and not of an individual nucleus.

The units of radioactivity are:

a) systemic - **Becquerel (Bq)** . 1 Bq is equal to the activity of a nuclide in a radioactive source, in which 1 act of decay occurs in a time of 1 s (1 Bq = 1 decay/sec). The unit was named in 1975 in honor of the French scientist A. Becquerel (A. Becquerel 1852-1908).

b) traditional (off-system) - **Curie (Ci).** The unit is named after the French scientists P. Curie and M. Skladowska-Curie and was introduced in 1910. Since 1956, it means such an amount of radioactive material that decays with an intensity of 3.7 10 ^{10} decays per 1 second, i.e.

$$1 \text{ Ci} = 3.7\ 10^{10} \text{ Bq},\ 1 \text{ Bq} = 2.703\ 10^{-11} \text{ Ci}.$$

The decrease in the number of active nuclei over time occurs in accordance with the law of radioactive decay, which is described by an exponential curve (Fig. 1) and is formulated as follows: equal fractions of active atoms are converted in equal time intervals. The law of radioactive decay has the following mathematical expression:

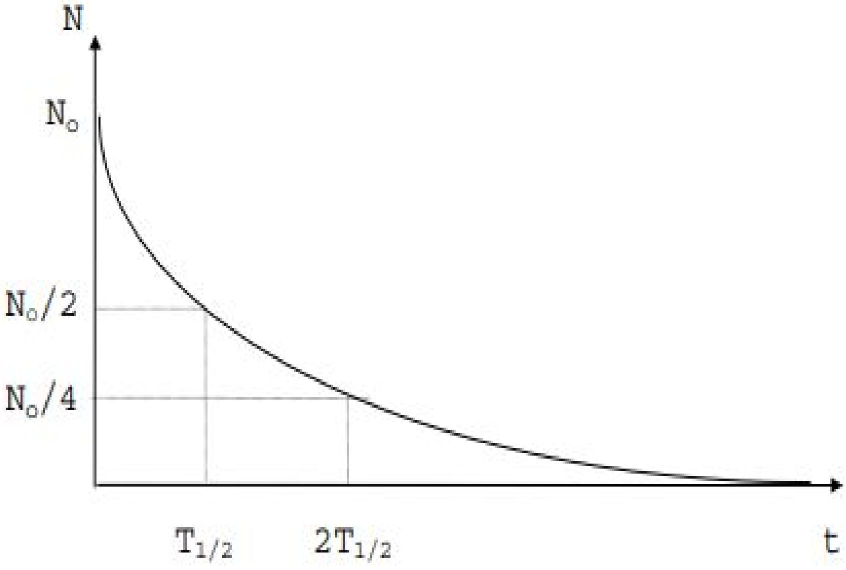
$$N_t = N_0 e^{\lambda t}, [1]$$

where N_0 is the initial number of radioactive nuclei; N_t is the number of active nuclei remaining after the decay time t ; e is the base of natural logarithms; λ is the decay constant, t - decay time.

The decay constant λ is related to the half-life T $_{1/2}$. The half-life is the time it takes for the number of radioactive nuclei to be halved. After mathematical transformations, the formula [1]takes the following form:

$$N_t = N_0 e^{\frac{-0,693t}{t_{\square}}} \qquad [2]$$

This formula is used for practical purposes when giving recommendations on the possibility of using food, water, etc. contaminated areas with radionuclides. since after 10 T $_{1/2}$ a practically pure medium remains (i.e., less than 0.1% of the original amount



remains
Fig.1. Change in the number of radioactive nuclei over time
radionuclide).

For example: I - 131 has a half-life of 8.05 days; Whole milk and locally produced leafy vegetables are forbidden to be used within 2-3 months after the release of radioactive iodine; for C_s-137, the half-life is 30.1 g: for Sr - 90, the half-life is 29.12 g; those. land contaminated with C_s-137 and Sr -9 0 can be used 300 years after the Chernobyl accident.

In nuclear physics, the following designation of nuclei is accepted: $_z X^A$. Here *X is* the symbol of a chemical element, Z is the charge number of the nucleus, A is the mass number of the nucleus. Z indicates the number of protons in the nucleus, the same as the atomic number of the element. A indicates the total number of runs and neutrons in the nucleus : $A = Z + N$. For example, one of the isotopes of uranium is written like this: $_{92}U^{238}$

This nucleus has $Z = 92$ protons. The total number of protons and neutrons is A = 238, and the number of neutrons in the nucleus: N = A - Z = 238 - 92 = 146.

Unstable nuclei undergo 4 main types of radioactive transformations: alpha - beta decay - transformation, gamma - transformation and spontaneous nuclear fission. The type of radioactive transformations is determined by the type of particles emitted during decay. The process of radioactive decay is always exothermic, i.e. comes with the release of energy. The original nucleus is called the parent nucleus (usually denoted in the diagrams by the symbol *X*), and the resulting nucleus after the decay is called the child (usually in the diagrams - the symbol *Y*).

1. ***Alpha (α) - decay.*** During α-decay, α-rays are emitted. Alpha rays are a stream of helium nuclei $_2He^4$, emitted from the nuclei of radioactive substances at a speed of 10^9 cm / s. The energy of α-particles is high and in different cases of α-decay reaches 4-9 MeW.

Shift rule for α decay :

$$_Z X^A \rightarrow {}_{Z-2}Y^{A-4} + {}_2He^4,$$

where *X* - means the chemical symbol of the decaying (parent) nucleus; *Y* is the chemical symbol of the resulting (daughter) nucleus;

A is the mass number; Z - serial number.

More than 200 alpha-active nuclei are known, almost all of them have a serial number greater than 83. The energy of α-particles of heavy nuclei is most often in the range of t4 to 9 MeW.

An example is the decay of the uranium isotope ${}_{92}U^{238}$, proceeding with the formation of thorium

$${}_{92}U^{238} \rightarrow {}_{90}T^{234} + {}_2He^4$$

2. Beta (β) - decay. Betta - the transformation of nuclei - is an intranucleon process, i.e. a single nucleon decays in the nucleus, an internal rearrangement of the nucleus ejected from the nucleus occurs during β - particle decay (electron e^-, positron e^+, neutrino v, antineutrino $\tilde{v}$)

There are three types of β-decay:

a) electronic ($\beta^{-¿¿}$)-decay

b) positron ($\beta^{+¿¿}$) decay,

c) electronic capture or K - capture.

a) ***Displacement rule for*** $\beta^{-¿¿}$***- decay*** . Electronic $\beta^{-¿¿}$-decay proceeds according to the scheme:

$$z X^A \rightarrow {}_{Z+1}Y^A + {}_{-1}e^0 + ¿,$$

One of the neutrons in the nucleus turns into a proton, an electron and an antineutrino, i.e. ${}_0n^1 \rightarrow {}_1p^1 + {}_{-1}e^0 + {}_0\widetilde{v}^0$.

where ${}_0n^1$ - neutron, ${}_1p^1$ - proton, ${}_{-1}e^0$ - electron, ${}_0\tilde{v}^0$ - antineutrino.

For example: ${}_{90}Th^{234} \rightarrow {}_{91}Pa^{234} + {}_{-1}e^0 + {}_0\widetilde{v}^0$.

Thorium ${}_{90}T^{234}$turned into protactinium ${}_{91}Pa^{234}$. The mass number of the nucleus does not change. The ordinal number of the core-product is increased by one.

b) ***Displacement rule for (*** β^+ ***) - decay*** *:*

$${}_ZX^A \rightarrow {}_{Z-1}Y^A + {}_1e^0 + {}_0v^0$$

One of the protons of the nucleus turns into a neutron, a positron and a neutrino, i.e.

$${}_1p^1 \rightarrow {}_0n^1 + {}_1e^0 + {}_0v^0,$$

where,. ${}_1e^0$- positron, ${}_0v^0$- neutrino.

For example: ${}_7N^{13} \rightarrow {}_6C^{13} + {}_1e^0 + {}_0v^0$

while nitrogen ${}_{7}N^{13}$ turned into carbon ${}_{6}C^{13}$. The atomic number of the daughter nucleus is one less than that of the parent.

c) ***Electronic capture or K-capture*** consists in the fact that the nucleus absorbs one of the electrons from the K-shell of the atom, as a result of which one of the protons turns into a neutron, while emitting a neutrino:

$${}_{1}p^{1}+{}_{-1}e^{0}\rightarrow {}_{0}n^{1}+{}_{0}v^{0}+hv$$

Displacement rule for K-capture:

$${}_{Z}X^{A}+{}_{-1}e^{0}\rightarrow {}_{Z-1}Y^{A}+{}_{0}v^{0}+hv$$

The place in the electron shell vacated by the captured electron is filled with electrons from the overlying layers, resulting in X-rays. An example of K-capture is the conversion of potassium to argon:

$${}_{19}K^{40}+{}_{-1}e^{o}\rightarrow {}_{18}Ar^{40}+{}_{0}v^{0}+hv$$

4) Gamma radiation. γ - radiation is a very short-wavelength electromagnetic radiation that occurs during nuclear processes. γ - radiation accompanies, for example, α - and β - decays. If the daughter nucleus that arises during these decays is in an excited state, then, passing into the normal state, it emits a γ - quantum.

The presence of the line spectrum of γ - radiation indicates the discreteness of the energy states of the nucleus, which correspond to the energy E_1, $E2$, $E3$. _ ,.... The state with the minimum energy E_1 corresponds to the ground state of the nucleus, and the rest to the excited state (Fig. 2). During the transition of an excited nucleus from a state with a high energy to a state with a lower energy, a portion of electromagnetic radiation is released in the form of a γ-quantum:

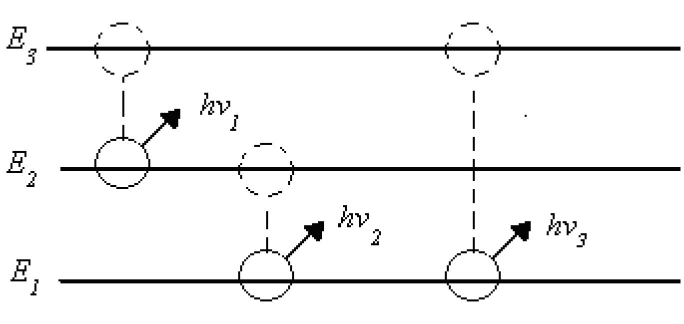


Fig. 2.

The frequency of gamma radiation for various nuclear processes ranges from 10^{19} -10^{22} Hz. This frequency range corresponds to energy from 0.04 to 40 MeW.

γ - quanta do not carry an electric charge and their rest mass is zero. As a result, they have a sufficiently high penetrating ability when interacting with a substance.

Penetrating and ionizing abilities of radioactive radiation.

Radioactive rays *(α,β* - particles and γ - photons), which have a high kinetic energy, penetrate into the substance, interact with the electrons of atoms and, knocking them out of the atoms, ionize the latter. Together with ionization, the excitation of atoms occurs, followed by emission in the optical range, as well as the activation of molecules, leading to photochemical reactions.

α - particles having a double elementary charge produce intense ionization and penetrate relatively shallow. The range in air, depending on the energy of the particles, ranges from 2 to 8,5 cm. In the tissues of the body, they penetrate to a depth of up to 0,1 mm. On 1 cm the run *α* -particle forms up to 30 thousand pairs of ions. Due to the small penetration depth (Fig. 3), a thin layer of any substance can serve as protection against *α* -particles: clothing, thick paper, cellophane, etc. The main danger *α* - particles are present when they enter the mucous membrane of the respiratory or digestive (when eating) tracts.

β - particles having a unit charge, as well as lower energy, produce much less intense ionization than *α* -particles, and therefore penetrate into the substance to a greater depth (Fig. 3). Depending on the energy, the range of *β*- particles in the air can be on the order of tens of centimeters to tens of meters. In body tissues, *β*- particles penetrate to a depth of several centimeters. In air, *a β*- particle forms from 50 to 250 pairs of ions per 1 cm run.

γ - rays are distinguished by a very high penetrating ability (Fig. 3). The range in the air is tens and hundreds of meters. In the tissues of the body, γ - rays penetrate to a great depth. The primary ionizing ability of a γ-photon is small, 1 смonly a few pairs of ions are formed on the way in the air. This is due to the lack of electric charge in gamma - photons. In the process of interaction of γ - photons with matter, secondary electrons and positrons appear. These particles, possessing a charge and sufficiently high energy, produce a sufficiently effective ionization. Therefore, the full ionization effect from the action of γ - radiation can be very significant. To protect against γ - radiation, only thick layers of the environment, earth, concrete, brick wall, as well as heavy metals, such as lead, several centimeters thick, can be used.

Fluxes of protons and neutrons, X-ray photons also have ionizing ability. All these radiations are united under the general concept of ionizing radiation.

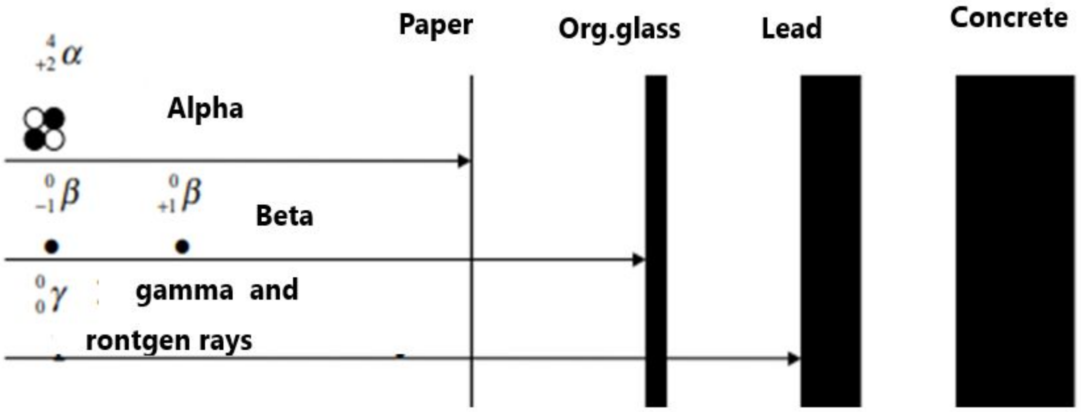


Fig. 3. Penetrating ability of different types of ionizing radiation.

Dosimetry of ionizing radiation

Dosimetry is the determination of the dose or its rate (i.e. dose per unit time).

To assess the consequences of exposure to ionizing radiation on substances, a quantity called *the absorbed dose is used.* The absorbed dose is numerically equal to the radiation energy absorbed by a unit mass of a substance. It is widely used in radiation physics, physics of protection and radiation safety, radiation chemistry, radiation technology, radiation biology and medicine. The SI unit of absorbed dose is the Gray, denoted by Gr. (1 Gr = 1 J/kg). One Gray is the energy of ionizing radiation in J, absorbed by a substance of mass 1 kg. If D and E, respectively, are the absorbed dose and energy, m is the mass of the irradiated substance, then with a uniform distribution of mass and energy: $D = E/m = E/V_{\rho}$

An off-system unit called a ***rad is also used*** . Rad is the dose of any type of ionizing radiation, at which 1 gr the radiation energy equal to 100 ergon is absorbed into the mass of matter (1 rad=100 ergon/g = 10^{-2} J/kg). The absorbed dose depends both on the nature of the substance by which it is absorbed, and on the nature and properties of the radiation.

Total exposure to a dose of 1000 rad is fatal to humans. Doses of 300-500 rad cause radiation sickness, 200-300 rad stop cell division, cause their death in many tissues of the body, and can also cause abnormalities in the offspring.

The rate of accumulation of the absorbed dose is characterized by a value called ***the absorbed dose rate*** or ***radiation dose rate*** .

The SI unit of absorbed dose rate is gray per second (Gr/s). 1 Gr/s = 1 W/kg.

Direct measurement of the absorbed dose in a substance, and especially in the depths of the tissues of a living organism, is difficult. In this regard, to predict the magnitude of the absorbed dose of X-ray or gamma radiation, the so-called ***exposure dose is used*** , which is the absorbed dose in the air. From the exposure dose, using the appropriate coefficients, one passes to the dose absorbed in the object.

Exposure dose - a quantitative characteristic of the field of an ionizing radiation source (gamma or x-ray) characterizing the amount of ionization of dry air at atmospheric pressure.

The unit of measure for exposure dose is coulomb per kilogram (C/kg). 1 C/kg is the exposure dose of X-ray or gamma radiation, at which, as a result of complete ionization on 1 kg dry atmospheric air, ions are formed that carry charges of one pendant of electricity of each sign.

The off-system unit roentgen is also used. X-ray (P- is the exposure dose of X-ray or - radiation, at which, as a result of the complete ionization of the mass in 1,293 kg atmospheric air, ions are formed that carry a charge of one electrostatic unit of the amount of electricity of each sign. 1P = 2.58 10^{-4} A / kg.

The rate of increment of the exposure dose is its power. US unit J/kg. Along with this, an off-system unit of exposure dose rate roentgen per second (R/s) is used. 1R/s = 2.58 10^{-4} A/kg.

For the purposes of radiation protection, the equivalent dose is widely used. The US unit is Joule per kilogram (J/kg). In practice, the scientific literature uses a special name for this unit - *sievert* (Sv). 1 Sv = 1(J/kg). Prior to the introduction of the US, the biological equivalent of rad - rem was adopted as the unit of dose equivalent. Equivalent dose - is a measure of the harmful effects of irradiation of a living organism.

The equivalent dose *D* is determined by the expression: $D_{э}=kD$ where D is the absorbed radiation dose in living tissue, for which the equivalent dose is determined, *k* is the radiation quality factor. The coefficient *k* is the regulated value of the relative biological effectiveness (RBE) of radiation. The RBE is used in biological research and is equal to the ratio of the absorbed dose of a reference radiation D to the absorbed dose of a given type of radiation D_x , for which the RBE is determined. (0BE \u003d D / D_X). In this case, the linear energy transfer (LET) serves as a characteristic of the radiation quality. The values of the radiation quality factor for external exposure, recommended by the International Commission on Radiation Protection, are given in Table. 1 depending on LET and types of radiation.

Table 1

LET, keV/µm of water	***k***	**Types of radiation**	***k***
3.5	1	X-ray γ - radiation and electrons	1
3.5 - 7.0	2		
7.0 - 23	2-5	Neutrons, protons and single charged particles with *m* >*1* a.m.u.	20
23-53	5-10		
53-175	10-20	α - particles, etc. multiply charged. particles	20

The risk of developing stochastic consequences of irradiation of the human body depends not only on the equivalent dose, but also on the radiosensitivity of tissues or organs exposed to radiation. The magnitude of exposure to ionizing radiation, used as a measure of the risk of long-term consequences of irradiation of the entire human body and its individual organs, taking into account their radiosensitivity, is called **the effective dose** (E). E is the sum of the products of equivalent doses in tissues and organs of the body and the corresponding weighting factors and is expressed by the ratio:

$$E=\sum_T W_T H_T,$$

where H_T is the equivalent dose in tissue or organ *T; W_T* is the weight factor of tissue or organ *T*.

The weighting coefficient (weight factor) WT characterizes the ratio of the stochastic damage to any organ or tissue to the risk of damage to the whole organism with uniform irradiation of the whole body. The risk of damage to the whole organism is taken equal to 1, i.e. the sum of the tissue weight factors is 1. The recommended weight factors W_T are given in Table 2.

Table 2.

Tissue weight multipliers

tissue or organ	W_T	tissue or organ	W_T
Gonads	0.20	Milk glands	0.05
Red bone marrow	0.12	Liver	0.05
Colon	0.12	Esophagus	0.05
Lungs	0.12	Thyroid	0.05
Stomach	0.12	Leather	0.01
Bladder	0.05	Other organs	0.05

When an individual is irradiated, one speaks of an individual dose. In case of radiation exposure to a group of people, collective doses are calculated:

a) **the collective equivalent dose (S_T)** in tissue T is used to express the total exposure of a specific tissue or organ in a group of individuals, it is equal to the product of the number of exposed individuals and the average equivalent dose in the organ or tissue;

b) the collective effective dose (S) refers as a whole to the exposed population. It is equal to the product of the average effective dose by the number of exposed persons in the group.

In determining collective equivalent and collective effective doses

The time for which the dose was received is not indicated. Therefore, when calculating collective before, there should always be a clear indication of the time period and group of persons for whom this calculation is made.

Collective doses are used to assess the radiation load on the population and the risk of developing stochastic consequences of ionizing radiation. The units of collective doses are **man *Sv and man*rem**.

Mathematical processing of measurement results

The process of radioactive decay has a statistical character. In addition, the processes of interaction of radiation with matter, which underlie the registration of radiation, also have a probabilistic nature. The statistical nature of the phenomena considered in nuclear physics leads to statistical errors.

The root-mean-square error is equal to the square root of the counted particles: $\Delta N = \sqrt{N}$

The relative statistical error is

$$\varepsilon = \frac{\Delta N}{N} \cdot 100\% \qquad \text{or} \qquad \varepsilon = \frac{100\%}{\sqrt{N}}.$$

From here you can find the number of particles that need to be counted to achieve a given accuracy

Therefore, to measure the average number of particles with a statistical error of 10%, 100 particles must be counted. In order for the statistical error to be 1%, it is necessary to count 10^4 particles, and to achieve an error equal to 0.1% - 10^6 particles, etc. In addition, it is necessary to take into account statistical errors associated with the measurement technique, instrument accuracy, etc.

Questions

1. What is the structure of the atomic nucleus?
2. Determine the number of protons and neutrons in the nucleus $_{92}U^{235}$
3. Write the displacement rule for α -decay and explain.
4. What transformation occurs inside the nucleus during β^- -decay?
5. Write according to the displacement rule β^+ - nuclear decay $_7N^{13}$.
6. Write according to the mixing rule k - capture the nucleus $_{19}K^{40}$.
7. What conditions are necessary for the occurrence of γ -radiation?
8. What is called absorbed dose? How is absorbed dose measured in SI?
9. What is an exposure dose?
10. What is the equivalent dose?
11. How is the root-mean-square error of counting radioactive particles determined?
12. How is the relative error in measuring the number of radioactive particles determined?

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