**MINISTRY OF HEALTH CARE OF UKRAINE**

**DONETSK NATIONAL MEDICAL UNIVERSITY**

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**METHODICAL instructions**

**FOR LABORATORY WORK ON DISCIPLINE**

**«Medical and biological physics»**

**PART І**

**FOR STUDENTS OF THE International faculty**

**FULL-TIME EDUCATION**

|  |  |
| --- | --- |
| Discipline | Medical and biological physics |
| Year | 1, 2 year(full-time, correspondence form) |
| Faculty | international |

**Kramatorsk – 2017**

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Methodical guidelines contain a list of initial skills needed for successful learning, the ultimate goal of studying and the materials necessary for self-examination and self-preparation. The instructions are prepared in accordance with the adopted in Donetsk national medical University system of manageing the quality of training.

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**Introduction**

**The subject** of the course "Medical and biological physics" is the study of physical and physico-chemical phenomena occurring at different levels of organization of biological systems and being the basis of physiological processes.

**The purpose** of the discipline is forming of the students ' systematic knowledge of the physical properties of matter and physical processes that occur in bio-objects, including the human body, and mastering of the fundamentals of mathematics and applied mathematical apparatus, which is a prerequisite for learning other academic disciplines and the acquisition of professional medical skills.

Tasks of the discipline:

* the study of the elements of Biophysics of the processes of life;
* the study of parts of physics and mathematics that reflect the basic principles of operation and capabilities of medical equipment used in the diagnosis and treatment of diseases;
* teaching students with mathematical methods that are used in medicine to obtain required information, to process results of observations and measurements;
* teaching students safety precautions when working with medical equipment that operates on the basis of some physical principle.

As a result of studying of discipline the student should **know**:

* the basic laws of physics, physical phenomena and relationships underlying the processes occurring in the human body;
* physical bases of functioning of medical equipment, device and usage of medical equipment;
* mathematical methods used to solve practical problems in medicine;
* safety rules when working with physical devices and medical equipment.

After studying the discipline, students **should be able**:

* to use educational and scientific literature, the Internet for professional activities;
* to predict the result of physical impacts on the human body;
* to use physical equipment;
* to make calculations according to the results of the experiment, to carry out basic statistical processing of experimental data;
* to draw up protocols for physical research and biomedical testing.

Laboratory work № 1

**Methods of error estimates for direct and indirect measurEMENT**

**Objectives**:

1. To learn how to handle the results of direct and indirect measurements taking into account random and systematic errors.
2. To learn to draw up a report on the implementation of laboratory work.
3. **Issues of input control**

1. What does it mean to measure a physical quantity?

2. What measurement are referred to as direct, indirect?

3. What types of errors do you know?

4. What quantities are called random? What are discrete and continuous random variables.

5. Why can the results of measurements be considered as a random variable?

1. **Brief theory**

Performing laboratory work is accompanied by measurement of physical quantities. A physical quantity is a quantitative measure of individual qualities of a physical phenomenon or the physical body. The physical quantity can be measured. Measuring the physical quantity is to compare it to the similar quantity of measurement, which has been chosen as a unit of measurement.

All physical units are standardized and grouped into the International System of Units (**SI**), which includes basic and derived units. The main units are the ones for which there are standards.

***Direct*** measurement is the one, in which the target value of the magnitude is found directly using a measuring device (pneumometer, tonometer, ammeter, thermometer, etc.).

***Indirect*** measurementis the one, in which the target value is found on the known relationship between this value and the quantities subjected to direct measurements (for example - the definition of object density by its geometrical dimensions and weight).

Measurements of physical quantities never make it possible to determine their true value. The result of each measurement differs from the true value of the measured quantity due to measurement errors. Measurement errors by the nature and causes of their appearance are divided into random, systematicand failures.

***Systematic errors*** lead to the same deviation of the measured value from the true value in all measurements. They arise from the use of faulty instruments, inaccurate or simplified measurement methods. Systematic errors can be reduced by replacing the used device for a device of a higher class of accuracy, or by refining the measurement method.

Systematic errors made in direct measurements, are caused mainly by the sensitivity of the instrument. Therefore, they are called tool or instrument errors. For the characteristics of most measuring devices the notion of reduced error is used:

,

Where *X* is absolute error or difference between the actual value of the measured quantity and the instrument reading, and *Xmax* is the largest value that can be measured on a scale of the device

According to the reduced error of measurement, all devices are divided into accuracy classes (0,1; 0,2; 0,5; 1,0; 1,5; 2,5; 4), which reflect the value of the reduced error percentage. Knowing the accuracy class of the instrument, it is possible to calculate its absolute instrument error

 (1.1)

In those cases, when the instrument accuracy class is not specified, the value of instrument error is taken to equal division value of the device (or half of the scale, if divisions are not very often and it is possible to determine which of the two neighboring divisions of the measured value is closer). The limit of permissible error of a digital measuring device is calculated according to the passport data that contains the formula for calculating the error of the given device. If no passport is available for the estimation of the error the unit of the least significant digit of the digital display is taken. For example, when on the indicator frequency 161.4 kHz is observed, the device error is 0.1 kHz.

***Failures*** are characterized by a clear and devoid of physical sense deviation of the recorded values from the other measurement results. These values are not repeated in repeated measurements, and should be discarded after testing.

***Random errors*** are characterized by equal probability to increase and decrease by the same amount of measurement results in relation to the true value of the measured quantity.

Random errors occur due to the imperfection of measuring instruments and the senses of the experimenter, and the influence of random factors, consideration of which is impossible. They can be reduced, but they cannot be eliminated completely.

Random error represents the difference between the measurements values and corresponding true values of this quantity. As random errors occur due to uncontrollable reasons, the measurement result is a random variable for which statistical methods can be used to determine point and interval estimates for the measured value. These methods vary depending on the accuracy of the measurement - direct or indirect.

Let be value of *a* got in a series of direct measurements. A set of values *a*1 can be considered to be a random sample of size *N* of all measurements carried out in the same conditions. The best point estimate of the measured value is a sample mean, which is calculated as the arithmetic mean of all measurements:

,

where . (1.2)

Interval estimate of the true value of the measured value is set by the interval centered at the point  and half-width

(1.3)

Where ) – Student's coefficient determined in accordance with table 1 of the Annex, for the confidence probability γ and the number of degrees of freedom of Student's distribution *f=N–*1and thevalue is called the standard deviation of the arithmetic mean and is calculated by the formula

. (1.4)

Interval estimate of the true value of the measured value is more reliable. In this case, the interval in which with a predetermined probability the true value of the measured gets is defined. This interval is called ***confidence interval***, and the probability that the true value of the estimated quantity lies within this interval is ***confidence probability*** γ or reliability. α=1–γ, characterizing the probability of missing the true value of the measured value in the selected confidence interval, i.e. the probability of error, called ***significance level***. The value γ is set in advance (usually in biomedical research the value *γ*=0,95=95% and *γ*= 0,99=99% are chosen), then the according to formula (1.3) the appropriate confidence interval is calculated., defined by formula (1.3) is called ***the half-width of the confidence interval*** of the measured value.

In addition to the variation in the measurements associated with random causes, each measurement of value ***а*** runs with the error of the instrument *δinstr*, determined by the formula (1.1). ***Absolute error***measurement is value, which determines the deviation from the true value, taking into account the random factors and instrument error. Absolute error is calculated according to the formula

 (1.5)

The result of the measurement is written in the form



means that with a confidence probability of γ the true value of the measured quantity belongs to the interval .

If only one measurement is carried or all measurements gave the same results, the absolute error is taken as equal to the instrument error.

To characterize the measurement quality ***relative error*** is calculated

, (1.6)

which shows what part the absolute error (error of measurement) takes from the value. The smaller the relative error is the more accurate the measurement is. Often the relative error is presented with percentage.

After calculating the absolute and relative errors of the measurement result is presented as

, α=0,05 (or α=0,01);

*ε* = …% (1.7)

The above-described method of determining the errors is also used for indirect measurements if they are conducted under changing conditions of experience.

Indirect measurements suggest that some value x is calculated by the formula

*x = f*(*a*, *b*, *c*, …), (1.8)

where quantities *а*, *b*, *с*, ... – the data obtained in direct measurements, reference data or numerical coefficients. It is assumed that for values determined with the direct measurements, statistical processing out is carried out in which according to the formulas (1.1 to 1.5) average values , as well as the absolute error of these values are calculated. For reference (tabulated) values absolute error is taken equal to the half of the last number position (e.g., π=3,14. The last digit is hundredths, respectively,   
Δπ = 0,01/2 = 0,005). As point estimates (most likely values) of the calculated value  (1.6) the value of the function from average values of measured values is taken:

 (1.9)

The error of indirect measurements Δ*x* is a consequence of the influence on the calculation result of the argument error, that is, values Δ*а*, Δ*b*, Δ*с*, *... .*Calculating the error values obtained in the indirect measurement, based on the fact that they are themselves much smaller than quantities () and so their   
influence can be estimated by the formulas of differential calculus. The absolute error of the variable x is determined by the formula:

 (1.10)

where the signs of the modules take into account the impossibility of mutual weakening of the influence of random errors of function arguments.

The relative error of indirect measurements, is also calculated by the formula (1.6), and the measurement result is written in the standard form (1.7).

1. **The practical part**

**Task 1**: measure lung capacity using a spirometer.

**Devices and equipment**: spirometer, ethanol for disinfection.

Spirometer is an instrument used to determine lung capacity.

**Progress**.

1. To get acquainted with the device spirometer. Get it ready for the work (disinfect the tip, set the arrow to the point of reference).
2. Take a deep breath and exhale the air to the maximum exhalation in spirometer. Record the lung volume (in liters) in table 1.1.
3. Repeat the measurement 5 times.
4. According to the formula (1.2) calculate the average value of lung volume . Write the result in table 1.1.
5. Calculate the absolute error of each measurement:. Write the result in the table 1.1.

*Table* 1.1

|  |  |  |
| --- | --- | --- |
| № experience | , liter | , liters |
| 1 |  |  |
| 2 |  |  |
| 3 |  |  |
| 4 |  |  |
| 5 |  |  |
| The average value |  |  |

1. According to the formula (1.4) calculate the standard deviation and write the result to a Table 1.1.
2. In table 1 of the Annex of«Student's coefficient»find the value of for *γ* = 95% and *f=N–*1=5–1=4.
3. Using the formula (1.3) calculate the absolute random error 
4. Find instrument error .
5. According to the formulas (1.5) and (1.7) calculate the absolute Δ*V* and *ε* the relative error of measurement.
6. Record the final result in standard form (1.7).

**Task 2**: measure the lung volume knowing the body surface area.

**Instruments and equipment:** Medical stadiometer, Medical Scales.

**Description of measurement methods:**

Lung capacity may be determined by various indirect methods. The most simple, but very approximate method is to determine the lungs cubage knowing the area of the body surface, which is proportional to the lung volume:

****

With men, one square meter of body surface area corresponds to an average of 2.5 liters of lung capacity (*A* = 2.5), women - 2 liters (*A* = 2).

Human body surface area (*S*) can be approximated by Duboys formula:

,

where *m* - the person's body weight in kilograms, *l* - height in meters.

**Progress.**

1. Measure the person’s weight (*m*0, kg)
2. According to the formula (1.2) calculate the average value of weight . Write the result in table below.
3. Calculate the absolute error of each measurement   
   .Write the result in the table below.

*Table* 1.2

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| № experience | *m*0, kg | *m*, kg | *l*0, m | *l*, m |
| 1 |  |  |  |  |
| 2 |  |  |  |  |
| 3 |  |  |  |  |
| Average value |  |  |  |  |

1. According to the formula (1.4) calculate the standard deviation   
    and write the result to a Table.In table 1 of the Annex of «Student's coefficient»find the value of  for γ = 95% and *f=N–*1=3–1=2.
2. Using the formula (1.3) calculate the absolute random error .
3. According to the formulas (1.5) and (1.7) calculate the absolute Δ*m* and *ε* the relative error of measurement with the instrument error =0,05 kg.
4. Measure the height (*l*0, m).
5. According to the formula (1.2) calculate the average value of height . Write the result in table.
6. Calculate the absolute error of each measurement.Write the result in the table.
7. According to the formula (1.4) calculate the standard deviation   
    and write the result to a Table 1.2.
8. In table 1 of the Annex of«Student's coefficient»find the value of forγ = 95% and *f=N–*1=3–1=2.
9. Using the formula (1.3) calculate the absolute random error .
10. According to the formulas (1.5) and (1.7) calculate the absolute Δm and ε the relative error of measurement with the instrument error =0,005*m*.
11. Record the value of weight and height in the standard form:

*kg*, *m*.

1. Using the Duboys formula determine the average value of the lung   
   volume .
2. Calculate the absolute error of indirect measurements according to the formula:

.

The calculations make Δ*А* = 0,05.

1. Calculate the relative error by the formula (1.7).
2. Record the final result of calculations. .
3. Compare the results obtained in tasks 1 and 2. Make a conclusion on the results of tasks execution 1,2.
4. **Issues output control**
5. What are the systematic errors caused by?
6. How is the systematic error of a measuring instrument determined?
7. What are random errors associated with?
8. How are instrumental and random errors to be taken into account?
9. What is the meaning of absolute and relative error?
10. How is the absolute error of indirect measurements calculated?
11. What is a confidence interval and a confidence probability?
12. How is the half-width of the confidence interval calculated?
13. What probability is sufficient to guarantee the measurement results in laboratory works?
14. What are the penalties? How are they taken into account when processing the measurement results?
15. What are the methods of measuring lung capacity? Which of these methods are most accurate and why?
16. What is the relationship between human height, weight, body surface area and lung volume?

Laboratory work № 2

**METHODS OF STATISTICAL PROCESSING of**

**SAMPLE DATA**

**Objectives.** To learn how to apply statistical processing of sample data.

1. **Issues of input control**
   1. What is the main task of statistical research?
   2. What is the General population and sample?
   3. What is the variation statistical series? How is it graphically presented?
   4. What is interval statistical series? How is it graphically presented?
   5. Which point estimates of parameters of sample, you know?
   6. What is interval estimation of the parameters of the sample?
2. **Brief theory**

Mathematical statistics develops methods for the study of mass random phenomena on the basis of analysis of experimental data obtained in the study of a relatively small group of these phenomena. Fundamental concepts of mathematical statistics are population and sample.

***Population*** is a set of similar objects, characterized by certain qualitative or quantitative characteristics and subject to statistical study. The number of elements of the population is called its size.

The part of the population, randomly selected for the study of a phenomenon is called ***sample***. The number of sample elements is called its size. In a series of experiments conducted with the sample, the analyzed value X takes certain values ***х****n* (*n*is the number of the experiment). Each obtained value of *X* is called ***variant***. These values are recorded in the order which they were received in the course of the experiment and called ***simple statistical series****.* For information about the statistical distribution of the investigated characteristic, described by the value *X*, a simple statistical series is transformed intoordered orinterval statistical series.

If the sample is examined for the quantity *X* representing the discrete random variable, then for statistical analysis of the sample statistical variation series is built. In the case when the studied characteristic is described by a continuous random variable *X*, for the statistical analysis interval statistical series is used. Since most biomedical parameters are continuous values, we shall consider the construction of interval statistical series.

For the construction of the interval series the entire area of the observed values of *X* is divided into a number of equal intervals and the number of characteristic values belonging to each interval is recorded (interval frequency). All of this can be represented as the following sequence of actions:

1. determine the maximum ***х***max and minimum ***x***min values of the studied random variable;
2. divide the interval [***x***max, ***x***min] into several equal intervals. The number of intervals *k* (generally not less than 5 and not more than 25) is approximately determined by the following empirical formulas:

, or,

where***n*** – the sample size;

1. calculate the width of the intervals

;

1. calculate the interval boundaries:

;

1. for each interval calculate frequency ***m****i*and (or) relative frequency   
   ***p***i = ***m***i / ***n***of getting the variant in this interval. Since some options may be a boundary of two adjacent intervals, usually one adheres to the following rules: the interval (***а***, ***b***) include options that satisfy the inequality ***а*** ≤ ***х***<***b***, so border option refers to the right interval.

The results of the implementation of paragraphs 1)-5) build table 2.1, which is called interval statistics series.

*Table* 2.1

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Intervals, *Х* | (***х***0, ***x***1) | (***х***1, ***x***2) | (***х***2, ***x***3) | … | (***х***k-1, ***x***k) |  |
| Frequency, ***m*** | ***m***1 | ***m***2 | ***m***3 | … | ***m***k |  |
| Relative frequency, ***р*** | ***p***1 | ***p***2 | ***p***3 | … | ***p***k |  |

In the last column the interval series is tested. The sum of the frequencies of variant getting in this interval must equal the size of the sample ***п***:

. (2.1)

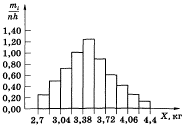
Accordingly, the sum of the relative frequencies should equal 1:

 (2.2)

Note that the expression (2.2) is similar to, the condition that must be met by the sum of the probabilities of events forming a complete group. So often the relative frequency is considered as the empirical probability that a continuous random variable X ***i***- th is in the interval.

Graphical representation of interval series is the histogram of frequencies or relative frequencies. ***Histogram of frequencies***is called the diagram consisting of vertical rectangles with base ***h***, and the height equal to the ratio . To build a histogram of frequencies on the x-axis the intervals of values of the studied indicator is put (top line of table.1) and they build rectangles height . Square of the ***i***- th rectangle is equal to the optionnumber on ***i***- th interval: . Therefore, the area of the histogram equal to the sample size.

The histogram of relative frequencies differs from the previous histogram by the fact that heights of rectangles equal to the ratio  - empirical probability density. Recall that  is a rough estimate of the probability that values of X are in the interval selected. The area of the histogram of relative frequencies must equal one. An example of histogram of relative frequencies is shown in figure.1.



*Figure* 2.1. The histogram of relative frequencies of body weight of newborns

Connecting the midpoints of the upper bases of the rectangles of the histogram of the relative frequencies with a smooth line,according to the sample you can obtain an approximate graph of the distribution function of the probability density  a random variable *Х*.

II. The main purpose of sampling is according to the computed numeric characteristics of the sample to determine the relevant characteristics of the populationas accurately as possible.

***Point estimate*** of characteristics of the population is made using the relevant numerical characteristics of the sample as the numerical characteristics of the population. For example, as a general meanthe sample mean is used, for the general variance the sample variance, etc. Such estimates are called point.

Point estimates of the population:

1. as an estimate of the general mean (mathematical expectation *M*(*X*)) the sample mean is used

; (2.3)

(in medical research this value is often denoted by the letter *μ*).

1. the best estimation of the General variance *σ*2 is the so-called sample corrected variance *s*2, calculated according to the formula

; (2.4)

1. the best estimation of the general quadratic mean deviation *σ* is the corrected sample standard deviation***s***:

. (2.5)

Recall that the variance σ2 and average quadratic deviation *σ* characterize the deviation of the observed experimental data from the mean value  (the mathematical expectation *M*(*X*) of a random variable *Х*).

***Interval estimation*** of the parameters of the population defines the interval in which with a predetermined probability the true value of the studied characteristic gets into. This interval is called ***confidence interval***, and the probability that the true value of the estimated quantity lies within this interval, - ***confidence probability*** γ. Value α=1–γ, characterizing the probability of error, is called ***significance level***. In biomedical studies choose γ = 0,95 = 95% orγ = 0,99 = 99% is chosen, then calculated the confidence interval is calculated.

Interval estimation of the general mean (the mathematical expectation *M*(*X*)) of the studied characterictic is the confidence interval

, (2.6)

where *μ* – the sample mean (2.3), а *δ* – the half-width of the confidence interval, the value of which, in general, depends on the distribution law of a random variable *X*. Forrandom variables obeying the normal distribution law, the half-width of the confidence interval is calculated by the formula

, (2.7)

whereisthe Student's coefficient for a confidence probability γ and the number of degrees of freedom of Student’sdistribution  (see table 1 of Annex), the standard deviation is calculated by the formula (2.5), ***п*** – the sample size. The result of interval estimation is written as:

, α=0,05 (or α=0,01).

When carrying out various studies several parameters of the objects of the sample are very often measured. For example, when examining the patient's height, body weight, blood pressure, etc. are measured. In such cases, the question of a possible connection between investigated parameters, which, in general, are random variablesnaturally arises.

The dependence of *Y* from the value *X* is called ***statistic dependence***, if each value of the variable *X* from the set of its allowed values corresponds to a set of valid values of *Y*. For example, people with different body mass (*Y*) can have height (*X*). And the change of variable *X* leads to a change in distribution *Y*.

When studying the statistical dependency, a particular interest is in the so-called ***correlation*** according to which change of value (*X*) leads to a change of the mathematical expectation of the other variable (*Y*).

The presence of correlation dependence between the considered parameters can be set qualitatively in the form of the correlation field, and quantitatively – by calculating the correlation coefficient.

For establishing correlations one experimentally determines the corresponding pairs of characteristic values *X* and *Y* for each surveyed object. The results are put in table 2.2.

*Table* 2.2

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| sign *Х* | ***x1*** | ***x2*** | ***x3*** | ***…*** | ***xn*** |
| sign *Y* | ***y1*** | ***y2*** | ***y3*** | ***…*** | ***yn*** |

Each pair of values (***хi***, ***yi***) on the *XOY*-plane corresponds to one point. The number of points equal to the size of the sample ***п***. Area on the plane XOY occupied by these points is called ***correlation field***.

By appearance of the correlation field it is possible to make qualitative conclusions about the nature of the relationship between the signs *X* and *Y*. If the form of the field is close to the circle (Fig. 2.2 a), the relationship between the features *X* and *Y* is absent. If the correlation field is elongated (Fig. 2.2 b), the correlation between variables *X* and *Y* exists, and the more elongated the correlation field, the stronger the correlation is.

*Y*

*X*

*Y*

*X*

а)

б)

*Figure* 2.2. A possible correlation of the field:

а) there is no correlation; b) there is a correlation

To quantify the presence of correlation sample correlation coefficient is calculated ***rху***:

, (2.8)

whereи - sample averages for characteristics *X* and *Y* (see formula (2.3)).

The values of the correlation coefficient can be both positive and negative, and. When it is believed that the relationship between *X* and *Y* is absent or very weak; when - the connection is reasonable; when - strong (close). If , between *X* and *Y* there exists a functional relationship   
*Y* = *f*(*X*). If , the relationship between the signs *X* and *Y* is direct, that is, with increasing of one variable the values of the other also increase. When there is the reverse relationship – with increase in one variable the values of another variable decrease.

The average error of the correlation coefficient can be found by the formula

. (2.9)

The value of the correlation coefficient is considered reliable if it is not less than 3 times bigger than its error: .

If the sample has a quite large and is representative, then the conclusion about closeness of the connection between the features obtained on the sample can be extended to General population.

1. **The practical part**

**Task 1.** Statistical processing of sample data.

1. Using the data of direct measurements of the laboratory work №1 (body weight, height and lung capacity) form a next sampling:

*Х*1 – the body weight of girls in the group;

*Х*2 – the body weight of boys in the group;

*Y*1 – the height of girls;

*Y*2 – the heightof boys;

*Z*1 – the lung capacity of light girls;

*Z*2 – the lung capacity of boys in the group \*.

Note: the sample is suitable for further work if its size is at least three objects (***n***≥3), body weight rounded to the nearest.

1. For a sample given by the teacher (*X*, *Y*, or *Z*) to build the interval series of distribution and a histogram of relative frequencies.
2. According to the formulas (2.3-2.5) make a point estimate of the studied parameter.
3. According to equations (2.6-2.7) to make an interval estimate of the true value of the measured value with a confidence level of γ = 0,95.

**Task 2.** Elements of correlation analysis.

1. For the pair of samples *X* and *Y* (body weight, height) to construct a correlation table (table. 2.2) and correlation field.
2. According to the formulas (2.3), (2.8) to compute the sample correlation coefficient.
3. By formula (2.9) to estimate the reliability of the correlation coefficient.
4. By referring to the correlation field and results of the points 2), 3) to makea conclusion about the correlation of the studied pairs of random variables.
5. **Issues output control**
6. Describe the stages of constructing a variational statistical series.
7. Describe the stages of constructing an interval statistical series.
8. What are the values used for point estimation of sample parameters? Write the appropriate formulas.
9. What is the essence of the interval estimation of sample parameters? How is the half-width of the confidence interval calculated?
10. What is the statistical connection between sample parameters?
11. In what cases can we talk about the correlation between the parameters of the sample?
12. What is a correlation field? How does the correlation between sample parameters affect the correlation field?
13. How is the correlation coefficient calculated?
14. What conclusions can be drawn from the analysis of the values of the correlation coefficient?
15. How is the probability of the correlation coefficient estimated?

**Laboratory work №3**

**DETERMINATION OF THE COEFFICIENT OF SURFACE**

**TENSION OF LIQUIDS**

**Objectives**.

1. To study the phenomenon of surface tension of liquids.
2. To determine the coefficient of surface tension of different liquids by the method of droplet detachment.
3. **Issues of input control**

1. What is the difference between properties of liquids properties of gases and solids?

2. What is the phenomenon of surface tension?

3. How are the phenomena of wetting and not wetting explained? What is contact angle?

4. What is the capillary phenomenon?

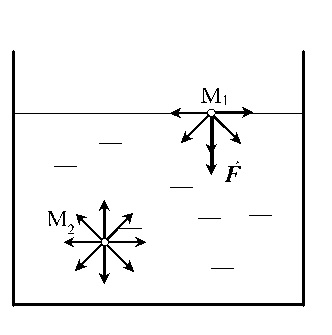
5. What is the significance of determination of surface tension in the medical practice?

**2. Brief theory**

By the physical properties liquids occupy an intermediate position between gases and solids. The liquid molecules are packed tightly enough, so the liquid is almost not compressible, and its density close to the density of a solid. Between the molecules of the liquid there are significant interaction forces slightly smaller than that of solids. Liquids, like solids retain their volume, however, as the gases take the form of the vessel in which they are located.

The liquid molecules make continuous random motion energy of wich is directly proportional to the temperature.

The most characteristic property of liquids is the presence of a free surface on the border with gas or solid that causes phenomena of a special sort, called surface phenomena. They are caused by special physical conditions in which molecules of the free surface of the liquid are. Every molecule of fluid is under influence of forces of attraction from the surrounding molecules, located from it at a distance of a few nanometers.

**

*Figure* 3.1.Molecular forces acting on the molecule *M*1 in the surface layer and the *M*2 molecule inside the volume of the liquid

Consider the forces acting on a molecule inside the liquid volume and on its surface. Molecule *M*2, located inside the liquid (Fig. 3.1), is under the action of about the same force by the surrounding molecules, therefore their resultant is close to zero.

For molecule *M*1 located on the surface of the liquid, the force of attraction from the molecules of gas are very small compared to the forces of attraction of molecules of the liquid, so the resultant of these forces is different from zero and is directed into the liquid perpendicular to its surface. This force tends to "drag" molecule *M*1 inside the volume of the liquid, but due to the dense packing of the molecules of the liquid such movement is impossible. Therefore, the molecules of the surface layer are under the influence of the molecular forces acting inside the fluid volume and the surface layer, like a stretched film, having a molecular pressure on the liquid.

In order to move molecule inside the volume of liquids, you must do work against the forces of molecular pressure. Consequently, each molecule on the surface of a liquid possesses additional potential energy compared with to the molecules inside the liquid. This potential energy is called surface energy.

It is obvious that the magnitude of the surface energy *Ws* is directly proportional to the number of molecules in the surface layer and, therefore, directly proportional to the area S of the free surface of the liquid

*Ws* =*σS*. (3.1)

The proportionality factor *σ* in equation (3.1) depends only on properties of the liquid and its temperature and is called the coefficient of surface tension. In the *SI* system the surface tension *σ* is measured in J/m2 or N/m.

Since any physical system tends to the state with the least possible in the given conditions potential energy, the free surface of the liquid tends to take the smallest possible area. For this reason, a drop of liquid in zero gravity takes a spherical shape that corresponds to the minimum surface for a given volume of liquid.

If on the free surface of the liquid to hold an imaginary line, then the resultant of molecular forces acting on this this line on one side, is directed along the tangent to the liquid surface and simultaneously perpendicular lines are possible break. This resultant force is called surface tension force, as it seeks to reduce the free surface area of liquid. It is obvious that this force is proportional to the length of the line ***l***:

** (3.2)

where *σ* is the surface tension coefficient expressed in *N/m* and equal to the force of surface tension acting on a length unit of the line.

The force of surface tension can be measured by limiting the liquid surface with the frame, one of sides of which can move freely (Fig. 3.2).

*Figure* 3.2.Measurement of surface tension

*F*

*F*

2*Ft*

*Ft*

*Ft*

On the moving side of the frame will be acted on by 2 surface tension forces*Ft* seeking to reduce the free surface area. For the balance of the movable side of the frame necessary to apply a force *F*, directed opposite to the forces of surface tension *Ft*: *F*=2*Ft*. By measuring the force *F*, it is easy to calculate *Ft*, and then use formula (3.2) to find the coefficient of surface tension *σ*.

The surface tension coefficient depends only on nature of liquid and its temperature. Away from the critical temperature (at which the difference between liquid and saturated steamdisappears), its value decreases linearly with increasing temperature. At a critical temperature the surface tension becomes zero (the difference between a liquid and its vapordisappears).

The phenomenon of surface tension of liquids has a direct impact on the processes of adhesion, the formation of fine particles of solids by crystallization, and liquids when they are sprayed, as well as merging of droplets or gas bubbles in emulsions, fogs, foams.

Surface tension forces determine the shape of biological cells and their parts. The change of the surface tension forces effects on phagocytosis (the capture of adjacent particles by cells), pinochets (capture of the liquid with the contained substances by the cell surface), processes of alveolar breath.

The coefficient of surface tension of various substances ranges from 0.01 to 2.0 *N/m*, with the cells it does not exceed 0.10 *N/m*. Substances dissolved in liquid, are able to lower and raise the coefficient of surface tension. Substances that reduce the surface tension of the solution, are called surface-active substances (surfactants). These include, in particular, the surfactant reducing the surface tension of the alveolar walls, thus providing the possibility of breathing.

The values of the coefficient of surface tension of some liquids at a temperature of 20 ° C are given in table 3.1.

*Table* 3.1.The values of the coefficient of surface tension of some liquids at a temperature of 20oC

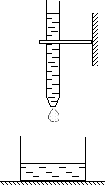
|  |  |  |  |
| --- | --- | --- | --- |
| Liquid | , *N/m* | Liquid | , *N/m* |
| Water | 0,0725 | Mercury | 0,47 |
| Ethanol | 0,022 | Bilis | 0,048 |
| blood serum | 0,056 | Milk | 0,050 |
| Aether | 0,017 | Urina | 0,066 |

Measurement of surface tension has a diagnostic value in the clinic. For example, in the urine, it is equal to 66 mN/m, and with the appearance in the urine of bile pigments is reduced to 56 mN/m.

1. **The description of measurement setup and method**

The surface tension can be determined by various methods: a method of droplet detachment, the method of separation ring, the method of measuring the maximum pressure in the air bubble (Rebinder is method), and according to the height of rise of liquid in capillary.

In medical practice method of droplet detachment is most often used. Schematic setup for this method is shown in Fig. 3.3 a.





*Ft*

а)

б)

*Figure* 33. Installation diagram and the forces acting on the drop

The formation and separation of drops of liquid when it runs out of small holes is the result of interaction of surface tension forces and gravity. The drop goes off when the force of gravity exceeds the force of surface tension that holds a drop on the tip of the burette (Fig. 3.3 b). Before the separation of the drops at the end of the capillary a constriction is formed, which then drops off. The force of surface tension around the circuit is equal:

, (3.3)

where  is the length of the border of the surface layer, *R* is the radius of the neck drops, which we believe is equal to the radius of the capillary of the burette.

At the time of separation drops will satisfy the condition of equilibrium of forces:

, (3.4)

where ***m*** is weight drops, ***g***= 9,81 м/s2 – acceleration of free fall.

From (3.3) and (3.4), we obtain the formula for computing the coefficient of surface tension:

.

The working formula has the form:

*σ* =  (3.5)

where ***m***** is the mass of empty vessel, ***m***** is the mass of the dish with «***n***» the number of drops.

1. **The practical part**
2. Using a Vernier caliper (or prompted by the teacher *R*=0,5) to determine the radius of the capillary.
3. Fill the burette with water from a syringe in the amount of 10-15 *ml*.
4. Use the scale to determine the weight ***m***1 of empty vessel for collecting fluid.
5. To set the velocity of the fluid not more than 10 drops per minute.
6. To fill the vessel with a certainnumber of drops (30-50) and to determine the weight ***m***2.
7. Experience with the test liquid is to be done forthree times, the results of the experiment are recorded in table 3.2.

*Table* 3.2. *The results of the measurements*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| № experience | Test liquid | *m1* | *m2* | σ | Δσ | ε |
| 1 | Water |  |  |  |  |  |
|  |  |  |  |
|  |  |  |  |
| The average value | |  |  |
| 2 | Sodium Chloride |  |  |  |  |  |
|  |  |  |  |
|  |  |  |  |
| The average value | |  |  |
| 3 | Athanol |  |  |  |  |  |
|  |  |  |  |
|  |  |  |  |
| The average value | |  |  |

1. According to formula 3.5 to calculate the value of surface tension for each experiment.
2. Calculate the arithmetic mean value of surface tension coefficient by the formula:

,

where are the results of the values of coefficients of surface tension in each of the experiments.

1. To calculate the absolute measurement error for each of the experiments according to the formula:

,

,



where is the results of the first, second and third changes, respectively.

1. To calculate the absolute error of the magnitude of the surface tension by the formula:

, (3.6)

where - the Student's coefficient determined in accordance with table 1 of the Annex for the confidence probability γ=95% and the number of degrees of freedom of Student's distribution , and in this work this value is taken equal to 2. Value is calculated using the formula:

,

where ***N***=3 is the number of tests.

The resulting value of the absolute error is recorded in table 3.2 into the cell "average value ".

1. Calculate the relative error by the formula:

.

1. Check the recording results of all calculations in the table 2.
2. Record the result for the surface tension coefficient of water in the form:



1. Drain the water, fill the burette with 0.9% sodium chloride solution (saline) and repeat paragraph 3-12.
2. Drain the fluids, fill the burette with athanol and repeat paragraph 3-12.
3. For each liquid, record the response in the form presented in paragraph 12.
4. **Issues output control**

1. Why does the surface layer of liquids have properties different from the properties of the rest mass of the liquid?

2. What do the forces of surface tension equal and how are they directed? How do the forces of surface tension manifest themselves?

3. What is the coefficient of surface tension? What units is it measured in? What does it depend on?

4. What are the pressure of the surface layer and the additional pressure under curved liquid surface caused by. Write down the formula of Laplace.

5. What is the phenomenon of gas embolism?

6. What is a surfactant? What is its role in the breathing process?

7. What forces act on liquid in the method of "droplet detachment "?

8. What factors affect the accuracy of the result when determining surface tension by the method of " droplet detachment "?

**Laboratory work №4**

### DETERMINATION OF THE KINEMATIC VISCOSITY OF LIQUID BY CAPILLARY METHOD

**Objectives:** To study medical viscometer and determining viscosity of fluid using it.

1. **Issues of input control**
2. What liquid is called perfect? What is the difference of a real fluid from the ideal?
3. What are the conditions of continuity of the liquid? Write down the continuity equation of fluid flow.
4. What is the ratio between the areas of the cross section and the velocity of the fluid?
5. Write down Bernoulli's equation. What is its physical meaning?
6. What is the velocity gradient? ...pressure gradient?

**2. Brief theory**

In a real fluid as a result of mutual attraction and thermal motion of the molecules internal friction, or viscosity takes place. We consider this phenomenon in the following example (fig. 4.1).

*V*1

*V*1

*V*2

*V*3

*V*4

*V*5

***x***

*Figure* 4.1. The flow of viscous fluid between the plates

Put a layer of liquid between two parallel solid plates. The "lower" plate is fixed. If moving the "upper" plate with a constant velocity *V*1, with the same speed will move the "top" of the 1st layer of fluid that is believed to be "stuck" to the top plate. This layer affects the bottom directly below it the 2nd layer, which is forced to move at a speed *V*2, wherein *V*2< *V*1. Each layer (in the allocation of *n* layers) transmits its movement to the underlying, layer having a slower speed. The layer directly "stuck" to the "lower plate remains stationary.

The layers interact with each other: the *n*-th layer accelerates the (*n*+1)-th layer, but slows down (*n–*1)-th layer. The forces acting between the fluid layers and aimed at a tangent to the surface layers, are called forces of internal friction, or viscosity. These forces are proportional to the area of interacting strata *S*, and the bigger they are, the greater their relative speed is. Internal friction power is calculated using Newton's equation:

. (4.1)

In the formula (4.1) *η* – coefficient of internal friction or dynamic viscosity (*η* dimension in the **SI** system – [PA∙s]);  – velocity gradient that characterizes the velocity change in the direction of axis *x* (axis *x* is perpendicular to the direction of movement of the layers of Fig.1).

The internal friction coefficient *η* depends on the condition and the molecular properties of the liquid (intermolecular forces). The viscosity is determined with the help of special devices – viscometers. The values of viscosity coefficient for some substances are presented in table 4.1.

*Table* 4.1*.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Viscosity of some substances | | | | | |
| Substance | Air | Water | Glycerin | Blood | Plasma |
| Temperature [°С] | 20 | 20 | 20 | 36 | 36 |
| Velocity [Pa ∙ s] | 1,8 ∙10-5 | 1∙ 10-3 | 1,5∙ 10-3 | 4∙ 10-3 | 1,5∙ 10-3 |

Blood viscosity increases with heavy physical work. In some diseases the blood viscosity increases to 23∙10-3 PA∙s (diabetes mellitus), while the other is reduced to 1∙10-3 PA∙s (TB). The viscosity of the blood manifests in such clinical parameters such as blood sedimentation rate (BSR).

For many fluids the viscosity does not depend on the velocity gradient, such liquids are described by the Neuton equation (4.1) and called *Neuton fluids*. They liquids are water, aqueous solutions, low molecular weight orga-night liquid (ethanol, acetone).

*Non-Neutons fluids* are the ones for which the viscosity depends on the flow regime and velocity gradient, respectively, they are not the equation (4.1). Such fluids include high molecular weight organic compounds, suspensions, emulsions. This is a liquid consisting of complex and large molecules. Thanks to molecules or particles cohesion, they form the spatial structure. Under other equal conditions, this viscosity is much larger than with the Neuton fluids. This is due to the fact that in the flow of such liquids, the external force is spent not only to overcome the Newtonian viscosity, but also to the destruction of structural formations.

Whole blood (elements suspension in the protein solution – plasma) is Non-Neutons liquid. Its viscosity is higher, the more slowly it flows. This is mainly due to aggregation of erythrocytes. In still blood red blood cells aggregate to form a so-called "coin bars", with the rapid blood flow units of red blood cells disintegrate and the viscosity decreases.

In the fluid flow may be laminar or turbulent. In Fig. 4.2 this is shown for one of the colored liquid jet that flows into the other liquid.

|  |
| --- |
|  |
| *Figure* 4.2*.* Laminar (*а*) and turbulent (*b*) flow of the flux fluid |

*Laminar* (*layered*) *flow –* flow, where the fluid layers flow without being mixed. Laminar flow is smooth, slow, well-arranged, regular flow of liquid. The speed of the various particles of the fluid, which in turns get into in some point of space, is the same. Such a movement is possible at low speeds of fluid flow in pipes with smooth walls and without sharp bends, at the same pressure over the cross section of the pipe.

*Turbulent* (*eddy*) *flow* is the flow at which the particle velocity of the fluid at each point is constantly changing, fluid particles come to the shaft motion that is accompanied by sound. Turbulent flow is chaotic and highly irregular, disorderly flow of liquid. The fluid elements travel in disordered complex trajectories, which leads to mixing of the liquid layers and to the formation of local eddies. In this case talking about flow in one direction or another is possible only in the average over some period of time.

Blood flow in arteries is normally laminar. In pathology, when the viscosity is less than normal, the blood flow in the arteries becomes turbulent. Turbulent flow is associated with additional loss of energy when fluid moves: some of the energy is consumed in chaotic motion, the direction of which is different from the primary flow direction, what in the case of blood flow leads to additional activity of the heart.

Turbulent blood flow can occur due to uneven narrowing of the lumen of the vessel (or a local bulging). Turbulent flows creates the conditions for the sedimentation of platelets and formation of aggregates.

The nature of fluid flow through the pipe depends on the properties of the fluid, the velocity of its flow, sizes of pipe. British physicist and engineer Osborne Reynolds studied the transition of laminar flow to turbulent. He experimentally showed that turbulence occurs when a certain combination of variables, which characterize the motion of the fluid exceeds a certain critical value. He introduced a dimensionless number later named after him the Reynolds number, characterizing the flow of liquid through the pipe (channel) and is calculated by the formula:

 (4.2)

where *ρ* is density of the liquid, *η* is viscosity, ***V*** is velocity of flow, ***D*** is diameter of the pipe. There is a critical value of the Reynolds number if the Reynolds number is greater than the critical value, the fluid flow is turbulent, if less – laminar. For smooth cylindrical pipes *Remax* = 2300.

In practice value, which is called the kinematic viscosity is often used:

. (4.3)

Then the Reynolds number can be written in the form

.

1. **Description of setup and measurement method**

3.1 Capillary method for the determination of viscosity coefficient

The instruments used for determining the viscosity of fluids are called viscometers. There is a huge variety in their designs. In medical practice to determine the viscosity of liquids the so-called capillary viscometers (рис. 4.3) are widespread.

1

2

*Figure* 4.3. Diagram of the device capillary viscometer.

Capillary viscometer (fig. 4.3) has a reservoir 1, from which a liquid flows through a calibrated capillary 2.

For fluid flow in the capillary equitable formula of Poiseuille, allows you to calculate the volume *V* of liquid flowing in time *t* through a pipe of radius r and length *l* with pressure difference at its ends ***∆p***:

. (4.4)

This formula is valid for laminar flow of viscous incompressible fluid in a straight pipe. Laminar flow regime of fluid in a capillary is realized due to the small bore diameter and low velocity of the liquid in the viscometer (see formula 4.2). For a stationary fluid flow (*V* = *const*) the pressure difference ∆*p* at the inlet and outlet of the capillary is determined by the weight of the liquid column:

, (4.5)

where *ρ* is the fluid density, *g* = acceleration of free fall. Taking into account the expressions (4.3), (4.5) Poiseuille's formula (4.4) takes the form:

. (4.6)

From the expression (4.6), we obtain the formula for determining the coefficient of kinematic viscosity

. (4.7)

Since the quantities *r* (radius of capillary 2 in Fig. 4.3), *V* (volume of tank 1) are constant for a given viscometer, the formula (4.7) can be represented as:

, (4.8)

where *K* is a constant, called the constant of viscometer.

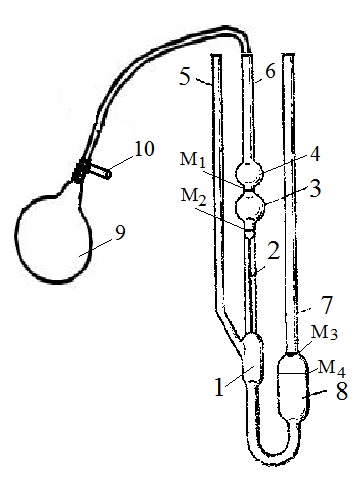
Formula (4.8) is used in the determination of kinematic viscosity using a capillary viscometer. In the derivation of formulas (4.7) the assumption of the constancy of the pressure drop in the liquid flow in the capillary is made and does not take into account the loss of pressure at the entrance of the fluid into the capillary (so-called entrance effect), so the value of the constant of viscometer is determined not by calculation according to the formula (4.7), but experimentally. For experimental determination the value of the constant of viscometer a reference fluid with a kinematic viscosity which *νe* known is used. The expiration time of the reference liquid from the viscometer τ is measured, and then determine the constant of the viscosimeter according to the formula:

.

Found on the producer factory viscometer constant shall be recorded in its passport, which is attached to the device.

3.2. Device description

In this lab, you use the viscometer capillary glass type VPI-1 with its hanging level (Fig. 4.4), which consists of measurement (3), which is bounded by two circular marks *M*1 and *M*2, the reservoir enters the capillary (2) and the reservoir (1) connected with a curved pipe (5) and tube (7). The latter has a reservoir (8) with the two marks *M*3 and



*Figure* 4.4

*M*4 which indicates the limit of filling the viscometer with the liquid. A tube (6) is connected to a blower (9) with crane (10). Fluid from the reservoir (3) through the capillary (2) flows into the tank (1) on the walls of the latter and forms on the lower capillary end "hanging" level. Measurement of viscosity using a capillary viscometer is based on determining the time of outflow a specified amount of liquid through the capillary from the measuring tank.

**4. The work order**

1. The liquid is poured into a clean viscometer through tube (7) so that it established the level between the marks *M*3 and *M*4.
2. Close the tube (5) with a finger.
3. Clamp the hose that connects the blower (9) with a tube (6), squeeze the pump (9) and close hole on the valve (10) with a finger.
4. Let the blower free, in that way to suck liquid into the tube (6) above mark *M*1, about half of the tank (4).
5. Open the pipe (5) and the hole on the valve (10).
6. Measure the time of outflow of the liquid level in the tube (5) from the mark *M*1 to position *M*2. Time that was measured, record in table 4.2. (When performing measurements, it is necessary to ensure that, until the liquid level approach to the *M*1 mark, there are no air bubbles in the capillary).
7. Repeat the experiment three times.

*Table* 4.2

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| № | *t,* s | Δ*t,* s | *ν,* m2/s | *Δν,* m2/s |  |
| 1 |  |  |  |  |  |
| 2 |  |  |  |
| 3 |  |  |  |
| Average value |  |  |  |

1. Calculate the arithmetic mean value of the outflow time of the liquid in the capillare:.
2. According to the formula (4.8) calculate the value of the kinematic viscosity of the liquid, which is used for the study. To calculate take: ***g***=9,81 m/s2, m.
3. Calculate the absolute measurement error for each of the experiments:
4. Calculate the value of the confidence interval by the formula:

,

where *n*=3 (number of experiments) is the student coefficient for a confidence level γ=95% and the number of degrees of freedom of student's distribution *f=n–*1 (see table 1 in the Annex).

1. Calculate the absolute error of the coefficient of kinematic viscosity

.

To calculate Δ***К***= 0,0001m, Δ***g*** = 0,01 m/s2.

1. Calculate the relative error of the coefficient of kinematic viscosity.
2. Fill in the table 2 and record the result in standard form:



**5. Issues of output control**

1. What is the physical cause of viscous friction viscosityin liquids and gases?
2. Write down Neuton's equation for viscous friction forces.
3. What are the units of viscosity.
4. What is Newtons and Non-neutons fluid? Give examples.
5. How does the viscosity of liquids depend on temperature?
6. Write and illustrate the formula of Poiseuille that describes the flow of viscous fluid through a channel with a circular cross section.
7. What causes the pressure drop in the liquid flow in the capillary viscometer?
8. What is meant by a device constant in working with the viscometer?
9. Why is not an absolute measurement of the dynamic viscosity of the liquid but its comparison with the viscosity of the reference liquid (most often distilled water)carried out with the aid of a capillary viscometer?What is the significance of the determination of the viscosity of biological liquids in medicine?

**Laboratory work № 5**

**PHYSICAL FOUNDATIONS OF CLINICAL METHOD   
OF MEASURING BLOOD PRESSURE**

**Objectives:** to study the technique of blood pressure measurement of blood, structure and working principle of the mechanical pressure gauge.

1. **Issues of input control**

1. What is Pascal's law?

2. What is hydrostatic pressure? Write down the formula for hydrostatic pressure.

3. Under what conditions is the laminar nature of fluid flow observed?

4. What is the difference between turbulent nature of the flow and laminar one? Under what conditions is there a turbulent flow of liquid?

5. What is normally the nature of the flow of blood in the vessels?

1. **Brief theory**

Blood pressure is the pressure that blood exerts on the walls of blood vessels, or the excess of the fluid pressure in the circulatory system over atmospheric. The most frequently measured is artery blood pressure.

At any point in the vascular system blood pressure depends on:

–atmospheric pressure;

–hydrostatic pressure *ρgh* due to the weight of the liquid column of height *h* and density *ρ*;

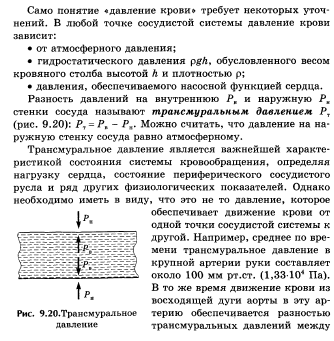
–pressure provided by the pump function of the heart.

The pressure difference between the internal and outer vessel wall is called a transmural pressure (Fig. 5.1):

.

We can assume that the pressure on the outer wall of the vessel is equal to atmospheric.

Transmural pressure is the most important characteristic of the circulatory system, determining the workload of the heart, the condition of peripheral vasculature, and several other physiological indicators.



*Figure* 5.1 Transmural pressure

However, you must keep in mind that this is not the pressure that provides the movement of blood from one point of the vascular system to another. For example, the time average of the transmural pressure in large arteries of the hand is about 100 mm Hg (1.33·104 PA). At the same time, the movement of blood from the ascending aortic arch in the artery is ensured by the difference in transmural pressure between these vessels, which is 2-3 mm Hg (300 PA).

Thetransmural pressure is significantly affected by the force of gravity createing a hydrostatic (weight) pressure. To illustrate this effect, imagine what would happen with the blood supply of vertically arranged human body, if the heart were not working. In this case, under the action of gravity the blood would flow into vessels of the lower body and the upper level would be in the region of the heart where the pressure is equal to atmospheric, i.e., transmural pressure would be equal to zero. At a certain height h, counted down from this level, the pressure would have a value of *ρgh*, where *ρ* is the density of blood, *g* is the acceleration of free falling, i.e. is determined only by the hydrostatic pressure.

Obviously, the hydrostatic pressure affects the distribution of blood in the vascular system of a living person. In this case, the outflow of blood from the upper body of the upright standing person is prevented by a number of physiological mechanisms. Besides the obvious heart works, it relates to a reflex constriction of the venous vessels of the legs in a standing position, which greatly reduces the ability of these vessels to stretch and store blood, as well as promotes venous return of blood to the heart.

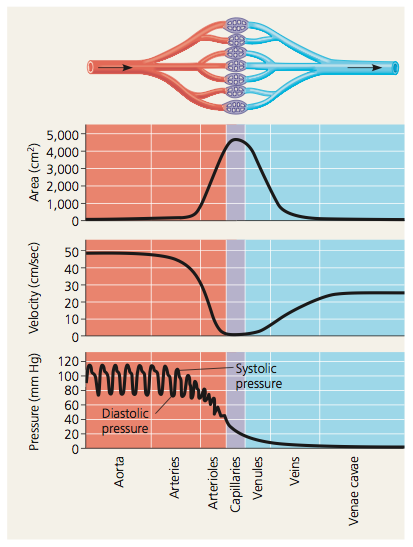
If vasoconstricting effect is weakened by illness or any external influences, then with the sudden stand-up the person may lose consciousness due to reducing venous return and reduced blood supply to the brain.

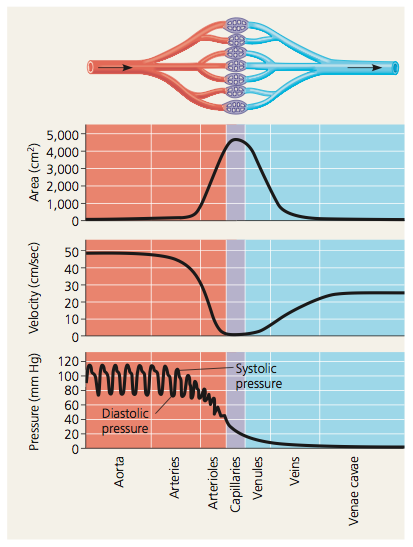
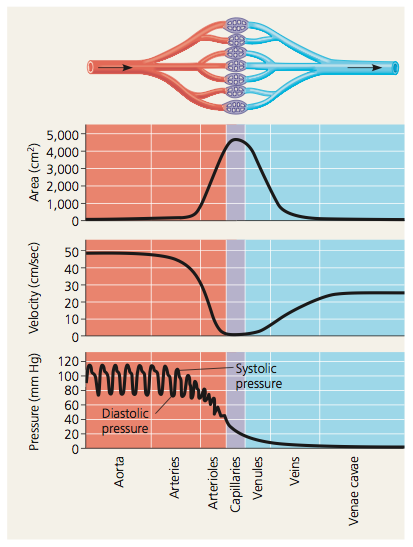
The measured transmural pressure due to exposure to the hydrostatic component can significantly depend on the selection of the place of its measurement and mutual arrangement of parts of the body. Thus, the transmural pressure in the arteries of the lower leg can be much greater than in arteries of hands.

In the clinical setting, measurement of blood pressure is usually produced in the area of the shoulder, i.e., at the level of the heart. Therefore, the hydrostatic component of the pressure in the brachial artery in this case is zero.

The movement of blood through the vascular system occurs due to excessive pressure caused by the heart above the atmospheric pressure. It is the specified pressure gradient which is the driving force of blood flow. The distribution of this pressure in the vascular system is shown in Fig. 5.2 (upper curve), which shows that in the aorta and large arteries, the pressure drop (the pressure difference at the beginning and end of the vessel) is not great.

In the arterioles there is a maximum pressure drop, since for the totality of the arterioles there is a large increase in the hydrostatic resistance *X*.





*Figure* 5.2. Distribution of pressure and velocity of blood flow in the vascular system

In the veins flowing into the heart, the pressure is below atmospheric. In large blood vessels pulse pressure variations occur, the amplitude of which decreases with the increasing degree of branching of the vascular bed and a decrease in the diameter of individual vessels.

Vascular system has a minimal cross-sectional area in the place of the aorta where there is the maximum amplitude of the pulse fluctuations and maximum linear blood velocity of 0.5 m/s (see Fig. 2, bottom curve). As we move to smaller blood vessels, the total area of their cross section increases in accordance with the terms of the continuity of the jet velocity the blood flow in them is reduced being in the capillaries about 0.5 mm/sec. In the venous part of the vascular system total cross-sectional area of the vessels decreases, which leads to an increase of blood flow velocity.

Artery blood pressure is the pressure of blood in major arteries of the body. There are two indicators of blood pressure:

–systolic (top) blood pressure (*SP*) is the level of blood pressure at the moment of maximum contraction of the heart, characterizes the state of the left ventricular myocardium and is equal to 100-120 mm Hg.

-–diastolic (bottom) blood pressure (*DP*) is the level of blood pressure at the moment of maximum relaxation of the heart, characterizes the tone of the arterial wall and is equal to 50-80 mm Hg.

Blood pressure is measured in millimeters of mercury, abbreviated mm Hg. The value of blood pressure 120/80 means that the magnitude of the systolic pressure is 120 mm Hg, but the value of diastolic blood pressure is 80 mm Hg. The difference between the systolic and diastolic pressures is called pulse pressure (*PP*). It shows how systolic pressure exceeds diastolic one what is required to open the semilunar valve of the aorta during systole. Normal pulse pressure is 35-55 mm Hg

Blood pressure of a healthy person is fairly constant, but it is always subject to small fluctuations depending on the phases of cardiac activity and respiration. Blood loss decreases blood pressure, and transfusion of large amounts of blood increases blood pressure. Blood pressure depends on age. With children, blood pressure is lower than with adults because the blood vessels are more elastic.

In the body blood flow is mostly laminar. However, under certain conditions, the blood flow can acquire turbulent character. So turbulence can occur in the cavities of the heart and their presence here is physiologically appropriate, since the resulting turbulence leads to mixing of portions of blood flowing from the pulmonary circulation into the left ventricle of the heart, and thus contribute to a more uniform oxygenation of the blood pushed then into the systemic circulation. A relatively small turbulence can occur in the aorta near the valves of the heart, because there is enough large value of the speed of blood flow. In intense exercise the rate of blood flow increases, which can also cause turbulence. With the viscosity decrease the turbulent nature of the fluid motion can occur also at lower speeds of its movement. Therefore, in some pathological processes leading to abnormal decrease in blood viscosity, blood flow in major blood vessels can become turbulent.

The presence of turbulence in the blood flow can be detected from the noise, listening with a stethoscope. Turbulent blood flow can also be created artificially by pinching the vessel by a harness, and then releasing. This phenomenon is used when measuring blood pressure.

1. **Description of measurement setup and method**

To measure blood pressure direct and indirect methods are used. The direct method is used in animal experiments; it involves inserting into the artery a needle connected to a manometer. Korotkov’s indirect method allows to measure your blood pressure with a very simple device.

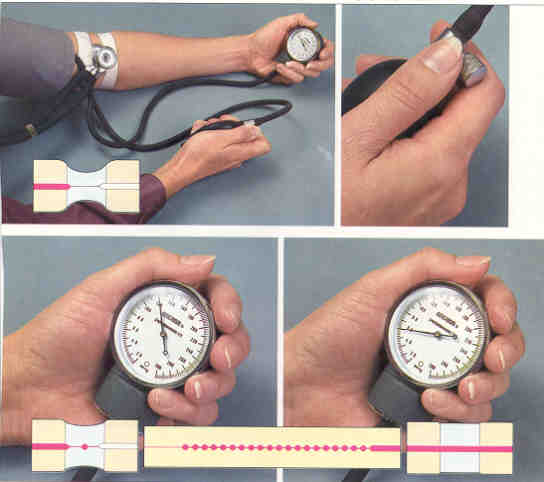
Korotkov's method is based on measuring the amount of pressure necessary to fully compress the arteries and the termination of blood flowin it. A device for measuring arterial pressure by Korotkov's method consists of a hollow rubber cuff, pressure gauge and pear for pumping air into the cuff.

Korotkov's method is the following (Fig. 5.3).

Around the arm between the elbow and shoulder cuff which can be filled with air is imposed. The cuff is applied always in the area of the brachial artery. This choice of locations for the cuff allows you to standardize the results, as the brachial artery in the arm is at heart level, and the measured pressure coincides with the pressure of the blood nearest to the heart part of the aorta.

First, the excess over atmospheric air pressure in the cuff is equal to 0, the cuff does not compress the soft tissue and artery. As pumping air into the cuff, the latter compresses the brachial artery and stops blood flow.

The air pressure inside the cuff, consisting of elastic walls, is approximately equal to the pressure in the soft tissues and arteries. This is the main physical idea of the bloodless method of pressure measurement. Releasing the air, reduce the pressure in the cuff and soft tissues. When the pressure equals the systolic, the blood will be able to get high speed through a very small cross-section of the artery, and the flow will be turbulent.



*Figure* 5.3. Measurement of blood pressure by Korotkov

Characteristic tones and noises that accompany this process, are heard to the doctor. At the moment of hearing the first tones pressure (systolic) is fixed. Continuing to reduce the pressure in the cuff, it is possible to recover the laminar flow of the blood. The noise stopped, at the time of its termination, register the diastolic pressure.

1. **The work order**

Students form pairs: the one experimented, the experimenter.

1. Clamp the cuff of the device on the arm above the elbow so that the lower edge of the cuff is approximately 2 cm above from the inner crook of the elbow and so that the tube is directed toward the palm. With proper application of the cuff between it and the hand one finger can be pushed.

2. Place the funnel of the stethoscope over the projection of the brachial artery below the cuff. Pre-define the place of maximum pulsation of the brachial artery.

3. Place the patient's arm on the table, close the faucet inthe valve, create a pressure in the cuff for 10-20 mm Hg higher than expected systolic blood pressure.

4. Gradually open the valve, set the speed of pressure reduction in the range of 3-8 mm Hg. a second and watch the gage.

5. Record:

a) the figure at the time of the appearance of the first sound in the brachial artery of the hand as an indicator of the maximum blood pressure;

b) the figure at the time of muting or disappearance of sounds in the artery as the index value of the minimum blood pressure.

6. Repeat the measurement for the second hand of the patient. The results are to be filled in in table 5.1.

7. Calculate the magnitude of the pulse pressure (PP) and record in table 5.2.

8. Repeat studies of blood pressure on both arms: a) immediately following the 10 fast squats; b) after five minutes of rest.

*Table* 5.1

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| The norm | | | | After load | | | | After a rest | | | |
| Right. hand | | Left. hand | | Right. hand | | Left. hand | | Right hand | | Left hand | |
| Syst. press. | Diast. press. | Syst. press. | Diast. press. | Syst. press. | Diast. press. | Syst. press. | Diast. press. | Syst. press. | Diast. press. | Syst. press. | Diast. press. |
|  |  |  |  |  |  |  |  |  |  |  |  |

*Table* 5.2

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Pulse pressure normal | | | | Pulse pressure after exercise | | | | Pulse pressure after rest | | | |
| Right. hand | | Left. Hand | | Right. hand | | Left. hand | | Right. hand | | Left. Hand | |
|  |  |  |  |  |  |  |  |  |  |  |  |

1. Explain the difference observed between the readings on the right and left hand, as well as readings after exercise and rest.
2. **Issues of output control**
3. What is pulse wave?
4. What is blood pressure?
5. What part of the cardio-vascular system is there the greatest drop in blood presuure? What is it caused by?
6. Give the definition of "blood pressure". List the devices to determine blood pressure. What does reading on the device 120/90 mean?
7. Give the definition of "systole" and "diastole".
8. Explain why with Korotkov’s method air pressure in the cuff can be considered equal to the pressure of the blood in the artery.
9. Explain why Korotkov’s method is not applicable for measuring the pressure of the water in the water supply?
10. Explain why the pressure of blood in the artery of the left hand is bigger than on the right one.
11. Are there any other methods (except for Korotkov’s) measurements of blood pressure?

Laboratory work № 6

**THE DETERMINATION OF THE THRESHOLD OF AUDIBILITY AND THE CURVE OF EQUAL VOLUME**

**Objectives:** to study the characteristics of sound waves and learn the basics of audiometry.

1. **Issues of input control**
2. What are oscillations? What characteristics of oscillation do you know?
3. What is a wave? What characteristics of waves do you know?
4. What types of waves do you know? What kind of waves are sound waves?
5. What is the physical reason for the propagation of the oscillations in an elastic environment?
6. What is the intensity of the wave?

**2.Brief theory**

The sound in the broad sense is elastic waves propagating in a gaseous, liquid and solid substances; in the narrow sense it is elastic waves in the frequency range from 16 Hz to 20 kHz, which are perceived by the human ear and create a human subjective sensation of sound. With age, the upper limit of this range decreases:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Age | Small children | 20 years | 35 years | 50 years |
| The upper boundary frequency, Hz | 22000 | 20000 | 15000 | 12000 |

Sound with a frequency below 16 Hz is called infrasound, and above 20 kHz is ultrasound, and high frequency elastic waves in the range of 109 to 1012 Hz is hypersound.

When describing the physical properties of sound one uses features common to all waves: speed, frequency, intensity, sound waves, and the description of the sensations that arise in the perception of sound,subjective characteristics of perception is pitch, timbre and volume are used. Subjective characteristics correspond to certain physical characteristics.

Physical characteristics of sound

**The speed** of sound is the speed of spreading of elastic waves in the environment. Its value depends on the elastic properties of the environment, and the density of the environment, for example, for longitudinal waves, which include sound in air, the speed of sound is calculated by the formula:

,

where *Е* is environment the elasticity modulus, *ρ* its density.

**Sound frequency** *f* is the frequency of vibration of the particles of the environment in which the sound wave spreads. **The period of oscillations** *T* is the time during which the particles do one complete oscillation. The frequency and period of oscillation are related by

.

**The wave length** *λ* is the distance between the points for which the phase difference between the oscillations is equal to 2π. Putting it simply, it is the shortest distance between the points of the environment, which move the same way. Wavelength has the meaning of the spatial period of the wave - through the segment of length λ the position of the particles, which oscillate, might be repeated. Wavelength is calculated by the formula:

.

Waves spreading in space, carry with them energy. **The intensity** of the wave *I* is the amount of energy that is transferred by the wave through area unit (S = 1 m2 per 1 second. The wave intensity is measured in W/m2. The intensity of the sound wave can be expressed using the sound pressure *P*:

,

where *ρ* is the density of the environment, and *V* is the speed of sound in the environment. Sound pressure *p* is the additional pressure arising from the passing of the sound waves in the environment; it is excess over the mean pressure in the environment.

Subjective characteristics of auditory sensations and their relationship to physical characteristics of sound.

From the point of view of sound perception by the human characteristics that are important are the height and timbre of sound, and sound volume.

а) The height and the timbre of the sound

It should be noted that naturally occurring sounds generally are the result of the superposition of sound waves (harmonics) with different frequencies. The set of frequencies present in this sound is called an acoustic spectrum.

If the sound formed by the superposition of waves, frequencies of which form a numerous set, its acoustic spectrum is discrete (liniar). This sound is called the tonal (musical), and it causes a feeling of sound with a specific pitch. The height of the tone sound is determined by the pitch frequency - the sound wave with the lowest frequency in the sound. The higher the frequency of the fundamental tone, the higher the pitch of the sound. The other frequencies included in the acoustic spectrum of the sound are called overtones. Overtones have frequencies that are multiples of the fundamental frequency. The relative intensity of the overtones determines the timbre of the sound. The same note played on different musical instruments, has a similar base tone but different relative sound intensity for overtones. -Due to this we can accurately determine by ear which musical instrument made that sound. In the simplest case the spectrum of the tonal sound has a single frequency - the main tone. The sound can be obtained using camerta.

If the sound has oscillations of all frequencies in a range from f1 to f2, the acoustic spectrum is called solid. Solid acoustic range has noise, human voice. In this case, the pitch of the sound is determined by the harmonic with the greatest amplitude.

b) The volume of the sound

The sound volume is determined by the intensity of the sound wave and, accordingly, sound pressure. Physiologically sound pressure is manifested as the pressure on the ear drum.

For the perception of sound by human there are two important values of sound intensity - the threshold of hearing and pain threshold. The upper limit of the sound volume perceived by a person is associated with the appearance of pain. The intensity of this sound is called a pain threshold. As well as the threshold of hearing, the pain threshold is different for different people, and depends on the frequency of the sound. At 1 kHz the threshold of hearing equals to an average of *I*0=10-12 W/m2, this intensity corresponds to a sound pressure *P*0=2·10-5 PA. For the same frequency the pain threshold *Imax*=10 W/m2 and *Rmax*=60 PA

Since the range of intensities of sound that people can hear is huge (*Imax*/*I*0=1013), to assess the intensity of the sound it is convenient to use a logarithmic scale. To do this, one introduces the value *L*, which is called the level of intensity that is proportional to the decimal logarithm of the ratio of sound intensity *I* to the intensity at threshold of hearing *I*0:

.

The sound intensity level *L* is measured in decibels (dB).

The use of a logarithmic scale to assess the level of sound intensity is well agreed with the psychophysical law of Weber-Fechner: if the intensity of the stimulus increases in a geometrical progression (that is the same number of times), the perception of this irritation increases arithmetically (i.e. by the same amount). This law cannot be called physical, as it characterizes a property of subjective experience. That’s why it is called psycho-physical (such a law is also true to evaluate visual sensitivity of the brightness of the light, tactile sensitivity of the skin, etc.).

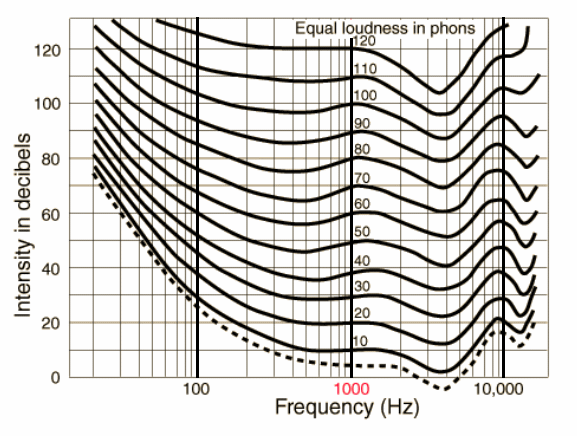
At first glance, it seems that the loudness of sound is measured in decibels. However, the subjective perception of sound intensity is connected not only with intensity but also with the frequency of the sound.

The sound level (volume) of *E* is associated with the level of intensity *L* with a ratio

,

where the coefficient *k* depends on the frequency and intensity of sound. To determine the sound volume do it the following way. For sound with a frequency of 1 kHz one introduces a unit for volume level-phone, which corresponds to an intensity level of 1 dB. For other frequencies the volume level is also expressed in the phones by the following rule: volume equals the sound intensity level (dB) at 1 kHz, which with the "average" person causes the same feeling of loudness as the given sound.

The dependence of volume on the intensity and frequency can be estimated from the curves of equal loudness (see Fig. 6.1). These curves show the change of intensity with frequency at a constant volume level. The lower curve (volume level 0 phones) corresponds to the volume of the weakest sounds that a man can hear, the threshold of hdearing. The upper curve corresponds to the pain threshold. Each curve corresponds to the same volume, but different sound intensity for different frequencies. Acoording toa separate curve of equal loudness it is possible to find the intensity which at certain frequencies causes the feeling of this volume.



*Figure* 6.1. Curves of equal loudnes

Method of assessment of hearing acuity is called audimetry. Usually the dependence of the level of intensity on the frequency at a volume that corresponds to the threshold of hearing, i.e., *EF*=0 is determined. The curve is called the spectral characteristic of the ear on the hearing threshold or audogram. When comparing a person’s audigram with audigram that was obtained on the basis of average data in humans with normal hearing one can diagnose diseases of the ear.

**3. Setup description and measurement method**

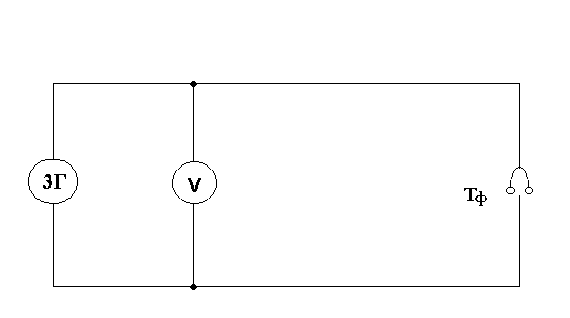
**Devices:** electric generator of sonic frequency (20-20, 000 Hz), the speaker or head phones, voltmeter.

The audiometer is a sound generator of pure tones of different frequencies and intensity. Fig. 6.2 shows a block diagram of audiometer.

The main part of this installation is the generator of electric oscillations of audio frequency is 3G.

*Figure* 6.2. The model of audiometer

*TF*



The voltmeter *V* is used to measure voltage of the generator.

In speaker or phones *TF* the transformation of electrical oscillations into sound ones occurs.

Since the intensity of the sound signal is proportional to the square of the voltage that is supplied to the phones from the generator, *I*~*U*, we can write:

.

Thus the intensity in decibels *LdB* can be estimated by the formula:

, (6.1)

where *U*is a voltage generator that provides a threshold loudness at frequency 1000 Hz, *U* is a voltage on generator that provides a threshold volume on the installed frequency.

**4.The work order**

1. Plug in your headphones and turn on the generator.

2.Install frequency 1000 Hz using the push button switches and handles on a scale of generator.

3. Set intensity level controller in the position in which you do not hear sound in the headphones.

4. Gradually increasing the intensity of the signal of the generator, achieve the threshold volume of barely noticeable, but well-recognized tone.

5. The voltage U at a frequency of 1000 Hz at the threshold of audibility *E*=0 record in the table 6.1.

6. According to the formula (6.1), rate the intensity value for frequency 1000 Hz and record it in table 6.1.

*Table* 6.1.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *f*, Hz | 1000 | 2000 | 3000 | 4000 | 5000 | 6000 | 7000 | 8000 |
| *U*, V |  |  |  |  |  |  |  |  |
| *Lb*, B |  |  |  |  |  |  |  |  |

7. Similar measurements of voltage and *L* calculations perform for frequencies 2000, 3000, 4000, 5000, 6000, 7000, 8000 Hz.

8. Data of measurements and calculations record it in the table 6.1.

9. According to the table build audiogram.

10. Compare the obtained data with the average that is shown in figure 6.1.

**5. Issues of output control**

1. What is a sound? Describe physical characteristics of sound.

2. List the characteristics of auditory sensation and specify their relationship to the physical one.

3. Formulate the law of Weber-Fechner.

4. Specify the units of intensity level and volume of the sound.

5. What is called audimetry?

6. What represents a curve of equal loudness?

7. What physical phenomena occur in the organs of human hearing?

8. What frequency range does the human ear hear better in? Justify your answer using the average audiogram.

9. Determine the intensity of sounds with frequencies *f*1=100Hz, *f*2=500Hz,

*f*3= 1000Hz, if the volume level of sounds is the same and equals to *E*=40 Phone?

10. Explain according to what voltage taken from the generator we can judge about the intensity of the audio signal, measured in decibels.

Annex 1

Table of «Student's coefficient»

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| n\γ | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% | 95% | 96% | 99% | 99,9% |
| 2 | 0,16 | 0,33 | 0,51 | 0,73 | 1,00 | 1,38 | 2,0 | 3,1 | 6,3 | 12,7 | 31,8 | 63,7 | 636,3 |
| 3 | 0,14 | 0,29 | 0,45 | 0,62 | 0,82 | 1,06 | 1,3 | 1,9 | 2,9 | 4,3 | 7,0 | 9,9 | 31,6 |
| 4 | 0,14 | 0,28 | 0,42 | 0,58 | 0,77 | 0,98 | 1,3 | 1,6 | 2,4 | 3,2 | 4,5 | 5,8 | 12,9 |
| 5 | 0,13 | 0,27 | 0,41 | 0,57 | 0,74 | 0,94 | 1,2 | 1,5 | 2,1 | 2,8 | 3,7 | 4,6 | 8,6 |
| 6 | 0,13 | 0,27 | 0,41 | 0,56 | 0,73 | 0,92 | 1,2 | 1,5 | 2,0 | 2,6 | 3,4 | 4,0 | 6,9 |
| 7 | 0,13 | 0,27 | 0,40 | 0,55 | 0,72 | 0,91 | 1,1 | 1,4 | 1,9 | 2,4 | 3,1 | 3,7 | 6,0 |
| 8 | 0,13 | 0,26 | 0,40 | 0,54 | 0,71 | 0,90 | 1,1 | 1,4 | 1,9 | 2,4 | 3,0 | 3,5 | 5,4 |
| 9 | 0,13 | 0,26 | 0,40 | 0,54 | 0,71 | 0,89 | 1,1 | 1,4 | 1,9 | 2,3 | 2,9 | 3,4 | 5,0 |
| 10 | 0,13 | 0,26 | 0,40 | 0,54 | 0,70 | 0,88 | 1,1 | 1,4 | 1,8 | 2,3 | 2,8 | 3,3 | 4,8 |
| 11 | 0,13 | 0,26 | 0,40 | 0,54 | 0,70 | 0,88 | 1,1 | 1,4 | 1,8 | 2,2 | 2,8 | 3,2 | 4,6 |
| 12 | 0,13 | 0,26 | 0,40 | 0,54 | 0,70 | 0,87 | 1,1 | 1,4 | 1,8 | 2,2 | 2,7 | 3,1 | 4,5 |
| 13 | 0,13 | 0,26 | 0,40 | 0,54 | 0,70 | 0,87 | 1,1 | 1,4 | 1,8 | 2,2 | 2,7 | 3,1 | 4,3 |
| 14 | 0,13 | 0,26 | 0,39 | 0,54 | 0,70 | 0,87 | 1,1 | 1,4 | 1,8 | 2,2 | 2,7 | 3,0 | 4,2 |
| 15 | 0,13 | 0,26 | 0,39 | 0,54 | 0,70 | 0,87 | 1,1 | 1,3 | 1,8 | 2,2 | 2,6 | 3,0 | 4,1 |
| 16 | 0,13 | 0,26 | 0,39 | 0,54 | 0,70 | 0,87 | 1,1 | 1,3 | 1,8 | 2,2 | 2,6 | 2,9 | 4,0 |

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Information resources

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