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МЕХАНІКА. МОЛЕКУЛЯРНА ФІЗИКА

(англійською мовою)

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CONTENTS

INTRODUCTION

Basic goal of the laboratory work manual on Physics is to enable students to learn important physical phenomena by experience. Laboratory work description does not try to give students a complete picture of the studied phenomena. Such presentation can only be achieved as a result of study of lectures and textbooks.

Large attention in the laboratory work manual on Physics for the students of technical professions is devoted to the handling of the measured results. Prior independent preparation, above all theoretical, is needed for successful completion of the work.

Every laboratory work is supposed to take two academic hours. Before the class a student must prepare a protocol of laboratory work and learn appropriate theoretical material.

During the class students do the necessary measurements, execute calculations and take the report to the conclusion. Measured results are discussed with a teacher and confirmed.

Fully designed report on laboratory work should be given to the teacher before the end of the class. It must include: title sheet, laboratory work number and name, list of devices and installations, purpose of work, drawing of the setting, calculation formulae, table of the measurement results and calculations, conclusions, as the result of the work. Graphs must be done on a millimeter`s paper.

If a student does not have time to support the laboratory work before the end of the class, he/she is allowed to design a report (graph) with the use of the computer programs (Excel, Origin) for the next class.

Laboratory work is considered done after the successful speech in support in front of a teacher (report explanation + mark for theoretical material).

Support of report: purpose of work + experimental method + conclusions.

Theoretical material: knowledge of the physical phenomena, which was studied in this laboratory work (laws, formulas).

1 ELEMENTS OF THE THEORY OF ERRORS

Measurement of physical quantities means their comparison with standard. There are two types of physical measurements:

1. ***Direct measurements*** are measurements when the investigated quantity $\boldsymbol{x}$ is taken by direct comparison with the standard performed with instruments.
2. ***Indirect measurements*** consist of direct measurements of physical quantities $\boldsymbol{x_1, x_2,.., x_n}$ and calculations made on this basis the investigated quantity $\boldsymbol{y}$ by a functional dependency $\boldsymbol{y = f(x_1, x_2 ,...,x_n)}$.

For example: measurements of length by a ruler or measurements of temperature with a thermometer are direct measurements. But measurement of volume of a cylinder by the value of its height $\boldsymbol{h}$ and diameter $\boldsymbol{d}$ (these are direct measurements) with functional relation $\boldsymbol{V=\pi d^2 h/4}$ is an indirect measurement.

All measurements can be performed only up to a certain degree of precision. Error of measurements is defined as a deviation of the result of measurements from the true value of a measured quantity.

Then, by definition

$$x-\Delta x \le x \le x+\Delta x \ ,$$

where $\boldsymbol{\Delta x}$ is absolute error of $\boldsymbol{x}$ measures.

The problems of the Theory of Errors are:

1. To get the investigated quantity.
2. To get the error of measurements.

There are two kinds of measurements errors: systematic errors and accidental ones.

Systematic error is defined as a component of error; its quantity is constant in all measurements or is being regularly changed during the repeated measurements of the physical quantity.

Accidental error is defined as a component of error that is changed irregularly during repeated measurements of the same physical quantity.

One should distinguish between ***blunder*** and above mentioned errors. Its value is essentially greater than the expected error in given conditions. For example, these errors may be received if an instrument is faulty, or if an experimenter is inattentive and so on.

1.1 Principal concepts of the theory of errors

We can't define the true values of a physical quantity. We can define only the interval (***x_{min}*** **,** ***x_{max}***) of the investigated quantity with some probability α. For example: we can affirm, that students' height may be defined between 1.5 m and 2.0 m with probability of 0.9. Then we can prove, that students' height may be defined between 1.6 m and 1.8 m with smaller probability of 0.6 and so on. Value of this interval is called ***the entrusting interval***. In Fig.1.1 interval of quantity being investigated ***x*** is represented.

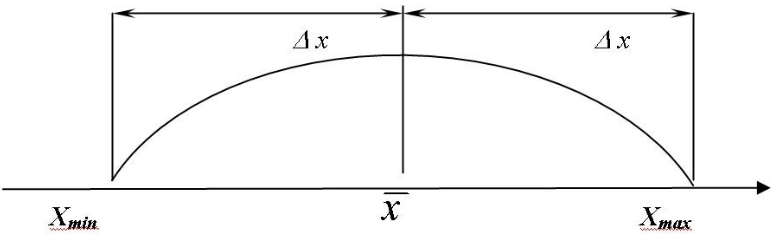

Figure 1.1

Where ***x*** is the most probable value of quantity being measured; ***Δx*** is the half width of the entrusting interval of the measured quantity with probability of α.

Therefore we can estimate, that true value of the measured quantity may be defined as $x = x \pm \Delta x$, with probability α,

or $$x - \Delta x \le x \le x + \Delta x \,.$$

If a quantity ***x*** has been measured ***n*** times and $x_1, x_2, ..., x_n$ are the results of the individual measurements then the ***most probable measured value*** or the ***arithmetic mean*** is:

$$\bar{x} = \frac{x_1 + x_2 + ... + x_n}{n} = \frac{1}{n}\sum_{i=1}^{n} x_i \quad . \tag{1.1}$$

The deviation $\Delta x_i = \left|\bar{x} - x_i\right|$ is called the ***accidental error (deviation) of a single measurement.***

$$\Delta\bar{x} = \frac{\Delta x_1 + \Delta x_2 + ... + \Delta x_n}{n} = \frac{1}{n}\sum_{i=1}^{n} \Delta x_i \tag{1.2}$$

is called ***the mean accidental deviation of the measurements***.

Mean root square is defined as

$$\Delta x_{sq} = t \cdot \sqrt{\frac{\sum_{i=1}^{n} (\Delta x_i)^2}{n \cdot (n-1)}} \quad , \tag{1.3}$$

where ***t*** – Student's constant for definite α and ***n***. The ratio of

$$E = \frac{\Delta x}{\bar{x}} \tag{1.4}$$

is called ***the relative error of measurement*** and is usually expressed in percents:

$$E = \frac{\Delta x}{\bar{x}} \cdot 100\% \cdot \tag{1.5}$$

1.2 Errors of instruments

Absolute error of instrumental **δ** is a deviation

$$\delta = a - X \quad , \tag{1.6}$$

where ***a*** is an index of an instrument; ***X*** is the true value of the quantity measured. Typically **δ** is quantity of the instruments minimum value scale. For example: the ruler error is **δ** = 1 mm.

Relative error of the measurement is the ratio of

$$\varepsilon = \frac{\delta}{X} \ . \tag{1.7}$$

It is usually expressed in percent

$$\varepsilon = \frac{\delta}{X} \cdot 100\% \ . \tag{1.8}$$

Brought error of the measurement or ***precision class*** is the ratio

$$\gamma = \frac{\delta}{D} \cdot 100\% \ , \tag{1.9}$$

expressed in percent. ***D*** is maximum value on the instrument scale.

For example: electric current is measured by the instrument with interval 0 ÷ 1 A, precision class is 0.5. This means, that ***D*** = 1 A, **γ** = 0.5 %, and

$$\delta = \frac{\gamma \cdot D}{100} = \frac{0.5 \cdot 1\text{A}}{100} = 5 \cdot 10^{-3}\,\text{A}.$$

If the instrument shows 0.3 A, then

$$\varepsilon = \frac{5 \cdot 10^{-3} A}{0.3A} \cdot 100\% = 1,7\%.$$

1.3 Errors of table quantities, count and rules of approximations

1. The error of table quantity is defined as

$$\Delta X_{table} = \alpha \cdot v, \qquad (1.10)$$

where, **α** is probability; **v** is half price of category from last significance figure in table quantity. For example: quantity π may be 3.14. In this case ***v*** = 0.005 and

$$\Delta X_{table} = \alpha \cdot 0.005.$$

If quantity π is 3.141 and v = 0.0005 then

$$\Delta X_{table} = \alpha \cdot 0.0005$$

and so on.

2. Error of count may occur when we measure quantity by an instrument. Typically, the error of count is half price of minimum value of instruments scale. For example a ruler has error of count v_l=0.5 mm.

3. Rules of approximation: quantity ***x*** may be approximated only to two significant figures, if the first significant figure is 1 or 2. In other cases, the quantity is approximated only to one significant figure. For example: ***x*** = 0.01865, approximated quantity is 0.019; ***x*** = 0.896, approximated quantity is 0.9 and so on.

1.4 Errors of direct measurements

Errors of direct measurements are defined as

$$\Delta x = \sqrt{(t_\infty \cdot \frac{\delta}{3})^2 + (\alpha \cdot v) \cdot^2}, \qquad (1.11)$$

if there is one measurement (***n*** **= 1**). And

$$\Delta x = \sqrt{(t_\infty \cdot \frac{\delta}{3})^2 + (\Delta x_{sq}) \cdot^2}, \qquad (1.12)$$

if there are several measurements (***n*** > **1**).

In these equations t_∞ is Student's constant, it may be defined from the table on the crossing of line with ***n*** and column with **α**; **δ** is error of an instrument; **v** is error of count, **v** =δ/2.

For example: the length of a body was measured three times:

x_i, mm	Δx_i, mm	$(\Delta x_i)^2$, mm^2
12.8	-0.466	0.217
13.6	0.334	0.111
13.4	0.134	0.018
$\bar{x}$ =13.266, n=3, t=1.4, t_∞=1, δ=1 mm.		

The error of this measurement will be:

$$\Delta x = \sqrt{(t_\infty \cdot \frac{\delta}{3})^2 + (\Delta x_{sq})^2} = \sqrt{(1 \cdot \frac{1}{3})^2 + 1.4^2 \cdot \frac{0.346}{3 \cdot 2}} = 0.473mm\,.$$

The relative error is

$$E = \frac{0.473}{13.266} \cdot 100\% = 3.56\%\,.$$

The final result is

x = (13.3 + 0.5) mm, α= 0.7 , E = 3.6 % .

1.5 Errors of indirect measurements

Let ***y*** be indirectly measured quantity, it is defined as $y = f(x_1, x_2, ..., x_n)$. $x_1, x_2, ..., x_n$ is defined as the direct measurements.

1. Errors of indirect measurements are defined as

$$\Delta y = \sqrt{\sum_{i=1}^{n}\left(\frac{\partial f}{\partial x_i} \cdot \Delta x_i\right)^2} \qquad (1.13)$$

if the functional dependence of investigated quantity is a polynomial.

2. Errors of indirect measurements are defined as

$$E = \frac{\Delta y}{\bar{y}} = \sqrt{\sum_{i=1}^{n}\left(\frac{\partial \ln f}{\partial x_i} \cdot \Delta x_i\right)^2} \qquad (1.14)$$

if the functional dependence of investigated quantity, is a monomial and we can define **Δy** as: $\Delta y = E \cdot \bar{y}$. For example:

1. If the functional dependence is $\prod = \frac{m \cdot V^2}{2} + m \cdot g \cdot h = f(m, V, g, h)$ then

$$\frac{\partial f}{\partial m} = \frac{\partial}{\partial m}\left(\frac{m \cdot V^2}{2} + m \cdot g \cdot h\right) = \frac{V^2}{2} + g \cdot h,$$

$$\frac{\partial f}{\partial V} = \frac{\partial}{\partial V}\left(\frac{m \cdot V^2}{2} + m \cdot g \cdot h\right) = m \cdot V,$$

$$\frac{\partial f}{\partial g} = \frac{\partial}{\partial g}\left(\frac{m \cdot V^2}{2} + m \cdot g \cdot h\right) = m \cdot h,$$

$$\frac{\partial f}{\partial h} = \frac{\partial}{\partial h}\left(\frac{m \cdot V^2}{2} + m \cdot g \cdot h\right) = m \cdot g$$

Then

$$\Delta \prod = \sqrt{\left[\left(\frac{V^2}{2} + g \cdot h\right) \cdot \Delta m\right]^2 + (m \cdot V \cdot \Delta V)^2 + (m \cdot h \cdot \Delta g)^2 + (m \cdot g \cdot \Delta h)^2} \ .$$

2. If functional dependence is $\prod = m \cdot g \cdot h = f(m, g, h)$,

$$\ln \prod = \ln m + \ln g + \ln h$$

$$\frac{\partial \ln \prod}{\partial m} = \frac{1}{m}$$

$$\frac{\partial \ln \prod}{\partial g} = \frac{1}{g}$$

$$\frac{\partial \ln \prod}{\partial h} = \frac{1}{h}$$

Then

$$E = \frac{\Delta \prod}{\prod} = \sqrt{\left(\frac{\Delta m}{m}\right)^2 + \left(\frac{\Delta g}{g}\right)^2 + \left(\frac{\Delta h}{h}\right)^2}$$

and

$$\Delta \prod = E \cdot \overline{\prod} \ .$$

The final result: $\prod = \overline{\prod} + \Delta \prod, \alpha =, E =$.

1.6 Graph presentation of the experimental results

Graph is built on the millimeter paper. In Fig.1.2 you can see an example of graph.

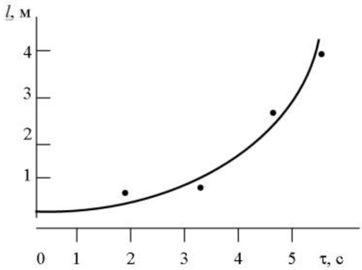

Figure 1.2

The experimental curve is drawn through the experimental points. This curve describes the experimental data.

Control questions

1. Definition of direct and indirect measurements. Examples.
2. Definition of the most probable value of the measured quantity ***x***.
3. What is called a relative error?
4. What is called an accidental deviation?
5. What is the equation of square mean of errors?
6. How do we define errors of instruments?
7. How do we define errors of table quantities and count errors?
8. Rules of approximation.
9. What is the equation of errors of direct measurements?
10. What is the equation of errors of indirect measurements?

Translator: S.P. Lushchin, associate professor, candidate of physical and mathematical sciences.
Reviewer: S.V. Loskutov, professor, doctor of physical and mathematical sciences.
Approved by the chair of physics. Protocol № 3 from 01.12.2008 .

2 LABORATORY WORK № 1. DEFINITION OF A BODY DENSITY

AIM: To calculate the density of a body and errors of direct and indirect measurements.

INSTRUMENTATION AND ACCESSORIES: Vernier callipers, metallic body.

2.1 System International units

A system of units, known as the System International (SI) units, is now used for all branches of physics. It is based on the meter as the unit of length, the kilogram as the unit of mass, the second as the unit of time, the ampere as the unit of electric current and the Kelvin as the unit of temperature. The unit of force in this system is the Newton and the unit of energy is the Joule.

For many years the meter (m) was taken as the distance between two lines on a particular platinum-iridium rod at 0^0 C kept near Paris. It is now defined as the length of a certain number of wavelengths in a vacuum of a particular orange radiation of the krypton-86 atom. Unlike the distance between the marks on the rod, the wavelength of the radiation from an atom is a constant. By definition,

1 m = 1650763.73 wavelengths of the above radiation.

The kilogram (kg) is the mass of a particular solid cylinder made of platinum-iridium alloy kept in Paris, known as the International Prototype Kilogram.

In practice, the following smaller units may also be used. The millimeter (mm), which is 1/1000 m. The centimeter (cm), which is 1/100 m The gram (g), which is 1/1000 kg. The second (s) was formerly 1/86400 th part of a mean solar day. This unit, used by astronomers, has now been replaced by an atomic unit. Atomic clocks are now used as standard clocks. Clock which measured the period of rotation of the earth to an exceptionally high order of accuracy and this showed clearly the irregularity in the rate of rotation of the earth. Cesium or atomic clocks are now used as standard clocks. The second is defined as the time for 9192631770 cycles of vibration of a particular radiation from the caesium-133 atom.

The mass per unit of volume of a substance is called its density:

$$\rho = \frac{m}{V}, \tag{2.1}$$

where ***m*** is the mass of the body and ***V*** is its volume. The volume of a parallelepiped equals to:

$$V = a \cdot b \cdot c, \tag{2.2}$$

where ***a, b, c*** are the width, the length and the height of the body. The volume of cylinder equals to:

$$V = \frac{1}{4} \cdot \pi \cdot d^2 \cdot h, \tag{2.3}$$

where ***d*** is the diameter of base of a cylinder; ***h*** is the altitude of a cylinder. Thus we can calculate the density of a parallelepiped with the formula:

$$\rho = \frac{m}{a \cdot b \cdot c}. \tag{2.4}$$

The density of a cylinder we can calculate with the formula:

$$\rho = \frac{4 \cdot m}{\pi \cdot d^2 \cdot h}, \tag{2.5}$$

where ***m*** is the given mass of the body.

2.2 Volume

Measurements of volume were originally based on the litter; this is defined as the volume occupied by a mass of 1 kg of pure water at its temperature of maximum density and at standard atmospheric pressure. The milliliter (ml) is 1/1000 of a liter. In the SI system, however, volumes are based on the cube whose side is 1 m; that is the cubic meter. This volume is written m^3. Volumes are also measured in cubic centimeters (cm^3), although this is not an SI unit. 1 cm^3 = 1 ml.

Water has a density (mass/volume) of 1000 kg/m^3 in SI units (equivalent to l g/cm^3); mercury has a density of 13 600 kg/m^3 in SI units (equivalent to 13.6 g/cm^3).

2.3 Vernier scale

P. Vernier showed how lengths can be measured accurately. He used a subsidiary scale, now called a vernier scale. Fig. 2.1a shows the vernier scale Y below the main scale X, which is graduated in centimeters and millimeters. 10 divisions on Y make 9 mm. Thus the length between each division on Y is 0 ÷ 9 mm, which is 0.1 mm or 0.01 cm less than the length of the divisions on X.

Fig. 2.1b shows the vernier scale Y moved to measure the length of a rod R. X

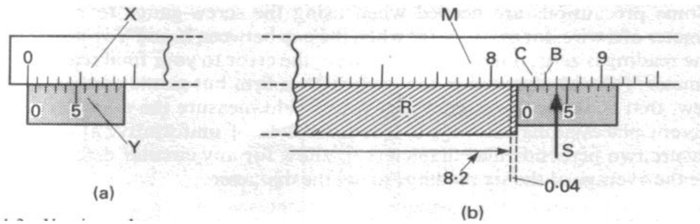

Figure 2.1 – Vernier scale

The length of ***R*** is greater than 8.2 but less than 8.3 cm. We now note the division ***S*** on ***Y*** which coincides with a division on *M*. This is the fourth division on ***Y***. The third division on ***Y*** is thus 0.01 cm in front of the graduation ***B***, the 2nd division on ***Y*** is 0.02 cm in front of the graduation ***C***, and so on. Hence the zero of ***Y*** is ***MM*** cm in front of the 8.2 cm reading on ***M***. Hence the length of ***R*** is 8.24 cm.

Fig. 2.2 shows a form of vernier calipers. The object measured is placed between the jaws ***X*** and ***Y***, and its length are read from the main and vernier scales as explained above.

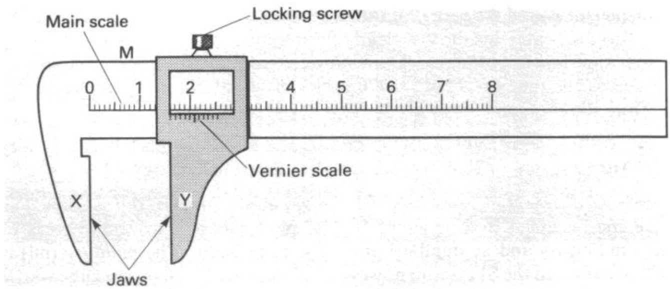

Figure 2.2 –Vernier calipers

2.4 Micrometer screw gauge

The micrometer screw gauge is an instrument for measuring accurately the diameters of wires or thin rods. It uses an accurate screw of known 'pitch' such as 0÷5 mm, shown inset in Fig. 2.3. This means that for one revolution of the screw the spindle X moves forward or back 0÷5 mm.

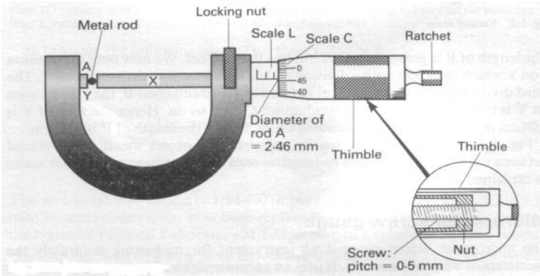

Figure 2.3 – Micrometer gauge

To measure the diameter of a wire or rod ***A***, one side is rested on the end ***Y*** and the thimble is turned until the end of the spindle ***X*** just touches ***A***. Further turning of the thimble does not make the spindle move forward because a ratchet stops excessive pressure on ***A***. A locking device is sometimes included so that the diameter reading can be read after **A** is taken out.

An engraved linear millimeters scale *L* shows the forward movements of the spindle. A circular scale ***C*** on the thimble helps to measure fractions of millimeters. In Fig. 4.4, 50 circular divisions = 0.5 mm, or 1 circular division = 0.01 mm. So from Fig. 4.4, diameter of rod = 2.0 mm (scale ***L***) + 46 × 0.01 mm (scale ***C***) = 2.46 mm

Some precautions are needed when using the screw-gauge to measure the diameter of a wire, for example (a) when the gap between X and Y is closed, check if the reading is zero; if not, add or subtract the error to your final reading of the diameter: (b) with the wire in the gap, make a firm but gentle contact with the screw, that is, do not over screw: (c) you should measure the diameter at three different places along the wire to allow for lack of uniformity; at each place, measure two perpendicular diameters to allow for any circular defect and then take the average of the six readings to get the diameter.

2.5 Measurement of mass

The mass of an object can be measured by comparing it with standard masses. These are derived from copies of the International Kilogram Mass. The chemical balance is used to compare masses in this way. Extremely sensitive balances can be designed. The National Physical Laboratory at Teddington in England has a balance which can measure to onemillionth of a gram. At this laboratory very precise weightings are carried out to assist science and technology.

School balances do not require such high precision. The design of chemical balances has altered so much in recent years that the types used will generally differ from school to school. The top pan balance gives direct reading of mass. It does this by comparing the unknown mass with movable known masses inside it. As in the common balance, the unknown and known masses are balanced using a lever arrangement.

If an object is taken say from London, England, to Lagos, Nigeria, or anywhere else in the world, and weighed on any other chemical balance, its mass will be exactly the same. So a chemical balance compares masses.

2.6 Measurement of weight

A spring balance provides a quick method of measuring weight. The object ***X*** (Fig. 2.4) is hung from the hook and the spring is then pulled out by a length proportional to the weight of ***X***. The weight of ***X*** is the force on ***X*** due to the earth's gravitational pull. The spring balance has a 'uniform' scale, that is equal divisions represent equal changes in weight along the whole scale. Weights are measured in Newtons (N) in SI units.

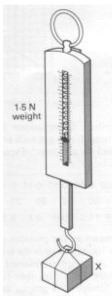

Figure 2.4 – Spring balance measuring weight

Unlike the chemical balance, the reading on the spring balance will vary slightly if the same mass is taken to different parts of the world. At the north; for example, it will weigh slightly more than at the equator. This is because gravitational pull is stronger at the poles and so the spring is stretched more. A spring balance measures weight, not mass.

2.7 Experimental Part

1. To measure length of the sides of the parallelepiped. One of the sides of it should be measured three times and two other sides are measured one time.
2. To fill results in to the table 2.1.

Table 2.1 – Dates for the parallelepiped

№	a_i, mm	Δa_i, mm	$(\Delta a_i)^2$, mm^2	b, mm	c, mm
1					
2					
3					

$\bar{a} =$ $\sum (\Delta a_i)^2 =$

Table 2.2 – Dates for the cylinder

№	d_i, mm	Δd_i, mm	$(\Delta d_i)^2$, mm^2	h, mm
1				
2				
3				

$\bar{d} =$ $\sum (\Delta d_i)^2 =$

where $\boldsymbol{a_i}$ $(\boldsymbol{d_i})$ is the result of measurements; $\bar{a}$ ($\bar{d}$) is the arithmetic mean; $\Delta \boldsymbol{a_i}$ $(\Delta \boldsymbol{d_i})$ is the accidental error (deviation).

3. To calculate the most probable meaning of density with the formula (2.1).
4. Mean root square:

$$\Delta a_{sq.} = t \cdot \sqrt{\frac{\Sigma (\Delta a_i)^2}{(n-1) \cdot n}} \quad . \tag{2.6}$$

5. At first it is necessary to obtain a formula for relative error:

$$E = \frac{\Delta \rho}{\bar{\rho}} = \sqrt{\left(\frac{\Delta m}{\bar{m}}\right)^2 + \left(\frac{\Delta a}{\bar{a}}\right)^2 + \left(\frac{\Delta b}{\bar{b}}\right)^2 + \left(\frac{\Delta c}{\bar{c}}\right)^2} \ , \tag{2.7}$$

where $\boldsymbol{\Delta m}$ is the error of a table quantity; $\boldsymbol{\Delta a}$, $\boldsymbol{\Delta b}$, $\boldsymbol{\Delta c}$ are half-widthes of the confidencal interval of direct measurements.

6. As we know:

$$\Delta m = \alpha \cdot v\,, \tag{2.8}$$

where **α** is a probability; **v** is a half price of category from last significance figure in a table quantity.

7. As value of ***a*** is measured ***n*** times (***n*** = 3) we use the formula:

$$\Delta a = \sqrt{\left(t_\infty \frac{\delta}{3}\right)^2 + (\Delta a_{sq.})^2}\,, \tag{2.9}$$

where t_∞ is the Student's constant; **δ** is an error of an instrument.

8. Quantities of ***b*** and ***c*** we obtain by direct measuring and we measure ***b*** and ***c*** one time (***n*** =1). So we have:

$$\Delta b = \sqrt{\left(t_\infty \frac{\delta}{3}\right)^2 + (\alpha \cdot v)^2}\,, \quad \Delta c = \sqrt{\left(t_\infty \frac{\delta}{3}\right)^2 + (\alpha \cdot v)^2}\,, \tag{2.10}$$

where **v** is an error of count; $\mathrm{v} = \frac{\delta}{2}$.

9. To calculate quantities of ***Δm, Δa, Δb, Δc***. Substituting them into formula (2.7), we find ***E***.

10. To find Δ***ρ*** from formula (2.7) in such a way:

$$\Delta\rho = E \cdot \overline{\rho}\,,$$

where ***E*** is the relative error, calculated by formula (2.7); $\overline{\rho}$ is the most probable meaning of the substance density, calculated by formula (2.1).

11. To write down the result of measurement after approximation using the form: $\rho = \left(\overline{\rho} \pm \Delta\rho\right)\frac{kg}{m^3} =$ $\quad \alpha = \ldots \quad$ $E = \ldots$ %.

Translator: S.P. Lushchin, associate professor, candidate of physical and mathematical sciences.
Reviewer: S.V. Loskutov, professor, doctor of physical and mathematical sciences.
Approved by the chair of physics. Protocol № 3 from 01.12.2008.

3 LABORATORY WORK № 2. MEASURING OF YUNG MODULUS OF METALS

THE AIM: to test Hook Law; to determine Modulus of Yung of steel wire.
INSTRUMENTATION AND ACCESSORIES: a slide gauge, a ruler, an indicator of lengthening, a set of weights, wire.

3.1 Introduction

Any body deforms under external stresses, i.e. changes in size and shape. When the action of force stops and the body restores its shape and size the deformation is called elastic. Under plastic deformation shape and size of a body is not restored when external stresses is eliminated.

Elastic deformation occurs when external force that creates this deformation doesn't extend a certain limit which is called ***elastic limit***. Under the effect of applied loading only insignificant change in the distances between atoms ore crystal clusters turning occurs. When stretching the distance between the crystal atoms grows and this distance decreases when compressing. For this case the balance of attraction and repulsion forces is violated, that is why the displaced atoms in the result of the action of attraction or repulsion forcers return to the initial state of equilibrium, and the crystals regain their original size and shape.

Let us apply external force $\boldsymbol{F}$ to the rigid rod fixed at one end (Fig. 3.1). Let the initial length $\boldsymbol{l}$ increased by $\boldsymbol{\Delta l}$. The ratio of the force to the cross section area - S is called the mechanical stress:

$$\sigma = \frac{F}{S} = \frac{mg}{S}. \tag{3.1}$$

For a cylinder specimen (wire) of the diameter d the cross section aria is:

$$S = \pi \frac{d^2}{4} \tag{3.2}$$

and the mechanical stress is:

$$\sigma = \frac{4mg}{\pi \cdot d^2}. \tag{3.3}$$

The value:

$$\varepsilon = \frac{\Delta l}{l} \tag{3.4}$$

is called relative deformation that is the ratio of absolute lengthening Δl to initial length l.

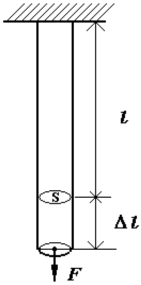

Figure 3.1

The experiment proves that linear dependency occurs between σ and ε in elastic deformation area. In fig.6.2 ***OA*** region is the elastic deformation area where Hook's Law is true:

$$\sigma = E \cdot \varepsilon . \tag{3.5}$$

In the ***AB*** region a plastic deformation takes place, i.e. in the case when $\sigma > \sigma_e$ residual deformations ε_r originates as soon as external forces stop acting upon. Stress σ_e is called limit of elasticity of the material.

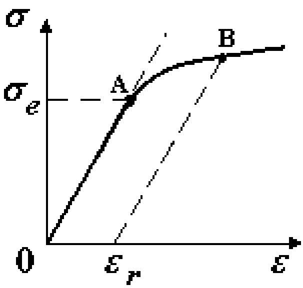

Figure 3.2

Relation (3.5) proves Hook’s Law, where ***E*** is elasticity module or Yung module that characterizes the elastic properties of a material. Yung module is equal to mechanical stress at which the rod length is doubled. The value of Yung’s modulus basically is determined by the type of crystal lattice, i.e. by the forces of atomic bonds.

The value of Yung’s modulus for some materials is shown in the table 3.1.

Table 3.1

№	Material	$E \cdot 10^9$, Pa
1	Steel	195 ÷206
2	Cast iron	150
3	Ti	116
4	Cu	101
5	Ag	83
6	Al	71
7	Mg	44
8	Glass	49 ÷ 78
9	Plastic	1.7 ÷ 1.9

3.2 Experimental device

The experimental device is shown in Fig.3.3.

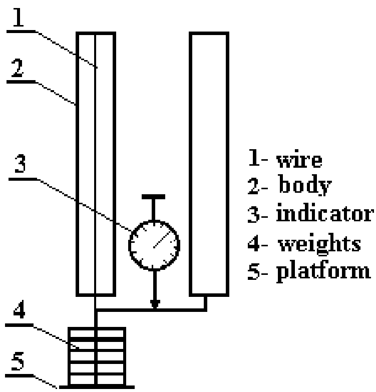

Figure 3.3

Wire 1 is fixed on body 2. Platform 5 is fixed to the end of the wire. Weights 4 are placed on the platform. Lengthening of the wire is measured with the indicator of lengthening 3.

3.3 Experimental part

1. Measure the diameter of the wire with the slide gauge and the length of the wire with a ruler.
2. Load the wire with 2÷3 weights to make it straight.
3. Fix the zero rotating the indicator scale.
4. Measure the lengthening of the wire $\boldsymbol{\Delta l}$ gradually loading it with the weights. Force ***F*** applied to the wire equals the sum of weights being loaded to the wire. Put down the results of the measurements ***m, F,*** $\boldsymbol{\Delta l}$ in a table 3.2. The length of the wire and its diameter are ***l*** = 1100 mm, ***d*** = 0,6 mm. Calculate mechanical stress and relative deformation according to formula 3.3 and 3.4. Put down the results in table 3.2.

Table 3.2

<table>
<tr><th>№</th><th>m, кg</th><th>F, H</th><th>$\Delta l, 10^{-2}$, mm</th><th>σ, MPa</th><th>ε</th><th>l , mm</th><th>d , mm</th></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td><td></td><td rowspan="10">1100</td><td rowspan="10">0.6</td></tr>
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</table>

5. Plot the dependency of **σ = *f*(ε)** accordingly to Fig. 3.4, i.e. draw the best straight line lying in the maximum density of experimental points. Choose any of two points 1 and 2 (but not from the table) to which values of σ_1, σ_2 and ε_1, ε_2 accordingly.

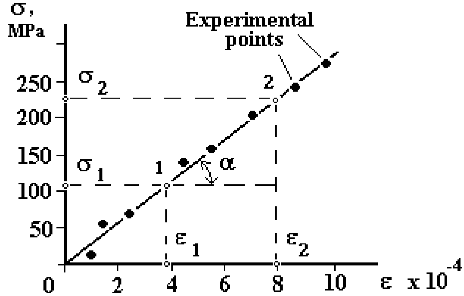

Figure 3.4

6. Calculate modulus of Yung by the formula:

$$E = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1} \tag{3.6}$$

Having such a method of determining the coefficient of proportionality (fig.3.4) between any values that laniary are related one to another, the all the totality of experimental data but not accidental value of any measurement is used. Using the data from table 3.1 determine the material of the wire.

7. Using the theory of errors estimate relative error of measurement Modulus of Yung by the formula:

$$\frac{\Delta E}{\bar{E}} = \sqrt{\left(\frac{\delta l}{\Delta \bar{l}_1}\right)^2 + \left(\frac{\Delta l}{\bar{l}}\right)^2 + \left(\frac{\Delta m}{\bar{m}_1}\right)^2 + \left(\frac{\Delta g}{\bar{g}}\right)^2 + \left(\frac{\Delta \pi}{\bar{\pi}}\right)^2 + \left(\frac{2\Delta d}{\bar{d}}\right)^2}\ , \tag{3.7}$$

where the value δl calculate according to the formula:

$$\delta l = \sqrt{\left(t_\infty \frac{\delta}{3}\right)^2 + (\alpha \upsilon)^2}\ , \tag{3.8}$$

where δ = 0.01 mm; $\upsilon = \frac{\delta}{2}$. According to the formula:

$$\Delta x_{табл.} = \alpha \cdot v \qquad (3.9)$$

calculate the values: $\boldsymbol{\Delta l}$ ($\upsilon = 1sm$), $\boldsymbol{\Delta m}$ ($\upsilon = 0.5g$), $\boldsymbol{\Delta g}$ ($\upsilon = 0{,}5m/s^2$), $\boldsymbol{\Delta\pi}$ ($\upsilon = 0{,}005$), $\boldsymbol{\Delta d}$ ($\upsilon = 0{,}05mm$).

6. On the base of relation **σ = *f*(ε)** make the conclusion if the Hook Law is true.

Control questions

1. What is the determination of eelastic and plastic deformations?
2. What is the determination of the mechanical stress and the relative deformation?
3. What type is the graph of experimental dependence $\sigma = f(\varepsilon)$?
4. What is the sens of Hook Law?
5. What is the physical sans of Yung modulus?

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4 LABORATORY WORK № 3. MEASURING THE COEFFICIENT OF INTERNAL FRICTION BY STOCKS' METHOD

THE AIM: to determine the internal friction coefficient of a liquid.
INSTRUMENTATION : a glass cylinder filled of oil, with a scale and two sliding rings AB and CD; metal balls; a vernier caliper; a stopwatch.

4.1 Theory

For a body falling in a liquid, the equation of motion is

$$m\vec{a} = \vec{P} + \vec{F}_A + \vec{F}_f \; . \qquad (4.1)$$

Here, $\vec{P}$ is weight, $\vec{F}_A$ is Archimedes' force and $\vec{F}_f$ is the force of viscous friction. Stocks established a resistance force experienced by a ball, which moves with low speed in a viscous medium. This force is

$$\vec{F}_f = -6\pi\eta r\vec{\upsilon} \quad , \qquad (4.2)$$

where η is the coefficient of viscous friction, r is the radius of the ball, $\vec{\upsilon}$ is the speed of motion. Criterion of "smallness" for the speed may be written as follows:

$$\mathrm{Re} \equiv \frac{\rho r}{\eta} << 1 \quad , \qquad (4.3)$$

where Re is the Reynolds number, ρ is the density of the medium. Projecting the forces onto z-axis pointed out vertically from the surface of the liquid, we obtain

$$m\frac{d\upsilon}{dt} = \frac{4}{3}\pi r^3(\rho_b - \rho)g - 6\pi\eta r\upsilon \quad , \qquad (4.4)$$

where ρ_b = 7800 kg/m^3 is density of the ball, ρ = 960 kg/m^3 is density of the liquid. Just after the ball has dipped into the liquid, it moves with acceleration, $\frac{d\upsilon}{dt} > 0$. The force of viscous friction increases until the moment of the force equilibrium

$$P - F_A - F_f = 0\,. \qquad (4.5)$$

From this moment, the ball falls with constant speed. Assuming $\frac{d\upsilon}{dt} = 0$ in (4.4), we obtain

$$\eta = \frac{2}{9} r^2 g \frac{\rho_b - \rho}{\upsilon}\;. \qquad (4.6)$$

4.2 Experimental part

1. Select 5 balls of approximately equal radius.
2. Fix the upper ring at the point of 0.1 m under liquid level. Place the lower ring CD at the distance 0.35 m from the upper one.
3. Measure radius r of a ball by the vernier caliper. Drop the ball into the cylinder. Switch on the stopwatch at the moment the ball passes by the upper ring, and switch off it when the ball moves near the lower ring. Put down time t of crossing the distance L between rings into the table 4.1.

Table 4.1

№	r, mm	L, m	t, s	υ, m/s	η, Pa · s
1		0.35			
2		0.40			
3		0.45			
4		0.50			
5		0.55			
	$\bar{r}$ =				

5. Plot the graph L versus t. Make conclusions about character of ball's motion. Determine the speed of motion υ as a slope of the line to the t-axis.
6. Substituting speed υ and average radius $\bar{r}$ into (4.6), calculate the coefficient of viscous friction η.
7. Find out what is the main error in determination of η. Estimate $\Delta\eta$.
8. Examine condition (4.3).

Control questions

1. What is the physical origin of viscous friction in liquids and gases?
2. Write down Stocks' formula for resistance force experienced by a ball moving in a viscous medium.
3. What is condition of validity for Stocks' method?
4. Obtain (4.6) starting from the equation of ball's motion.
5. Substituting into (4.6) reasonable values for radius and speed, estimate the coefficient of viscous friction of water (ρ = 1000 kg/m^3).

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5 LABORATORY WORK № 4.1 ELASTIC IMPACT OF BODIES

THE AIM: to study the laws of perfectly elastic impact.
INSTRUMENTATION AND APPLIANCES: two balls suspended to rods, a scale for the angles measurements, a device ПС02-2M to count electric pulses and a generator of electric pulses.

5.1 Task

1. Calculate a mean impact time $\vec{\tau}$.
2. Calculate a mean impact force $\vec{F}$.
3. Calculate the absolute and relative errors of $\boldsymbol{\tau}$ and ***F*.**
4. Draw the conclusions.

5.2 Short theory

THE IMPACT is interaction of two or more bodies that takes place during a very short time. A magnitude of internal forces appearing in bodies system during the impact is relatively big, so the external forces acting on the bodies at this moment of time can be neglected. This enables to apply the law of conservation of momentum (law of conservation of impulse) for studying the phenomena of the body's collision because a system of interacting bodies is isolated

PERFECTLY ELASTIC IMPACT is interaction of two bodies acting with elastic forces at each other, no mechanical energy of the system being transformed into thermal energy (heat). In this case we can apply both the law of conservation of momentum and mechanical energy.

PERFECTLY INELASTIC IMPACT is interaction of two bodies resulting in partial transformation of the mechanical energy into heat. The bodies move after collision as whole body. In this case we can not apply the law of conservation of mechanical energy, but we can apply the law of conservation of momentum and total energy of system. Hence we may write:

a) for perfectly elastic impact

$$m_1 \cdot \vec{V}_1 + m_2 \cdot \vec{V}_2 = m_1 \cdot \vec{V}_1' + m_2 \cdot \vec{V}_2,$$

$$\frac{m_1 \cdot V^2{}_1}{2} + \frac{m_2 \cdot V^2{}_2}{2} = \frac{m_1 \cdot (V_1')^2}{2} + \frac{m_2 \cdot (V_2')^2}{2},$$

where $\boldsymbol{m_1}$ and $\mathbf{m_2}$ are the masses of interacting bodies; $\boldsymbol{V_1}$ and $\boldsymbol{V_2}$ are the velocities of the bodies before the impact; v_1' and v_2' are the velocities of the same bodies after the impact.

b) for perfectly inelastic impact

$$m_1 \cdot \vec{V}_1 + m_2 \cdot \vec{V}_2 = (m_1 + m_2) \cdot \vec{U},$$

$$\frac{m_1 \cdot V^2{}_1}{2} + \frac{m_2 \cdot V^2{}_2}{2} = \frac{(m_1 + m_2) \cdot U^2}{2} + Q,$$

where $\boldsymbol{U}$ is the velocity of the bodies system after the impact; $\boldsymbol{Q = E_1 - E_2}$ is the mechanical energy turned into heat ($\boldsymbol{E_2}$ and $\boldsymbol{E_1}$ are the mechanical energy of the system before and after the impact.

5.3 Elastic impact

The experimental installation to study the perfectly elastic impact consist of two rods with suspended balls, the scale for measurement of angles, a generator of elastic pulses and a device to count the pulses. Electric pulses pase through the balls of there is a contact between those balls. It is possible to obtain the bodies interaction time (impact time) if we know the numbers $\boldsymbol{N}$ of electric pulses having passed the balls during impact time and the same numbers $\boldsymbol{N}$ having passed at a second. Evidently can be calculated by the formula

$$\tau = N/N_0 \qquad (5.1)$$

Mean balls interaction force (mean impact force) can be calculated by the formula, which shows change of momentum of the body and impulse of the force

$$F \cdot \Delta\tau = \Delta p,$$

where $\boldsymbol{F}$ is a mean impact force, $\boldsymbol{\Delta\tau}$ is the mean impact time; $F\Delta\tau$ is the impulse of the force; $\boldsymbol{\Delta p}$ is the change of body momentum.

Hence

$$F = \Delta p/\Delta\tau = m\left(v - v_0\right)/\Delta\tau,$$

where $\boldsymbol{v_0}$ is the body velocity before the impact, $\boldsymbol{v}$ is the body velocity after the impact($\boldsymbol{v} = 0$ in our case). According to the law of conservation of mechanical energy

$$mgh = mv^2/2$$

and

$$V = \sqrt{2gh}\ ,$$

where $\boldsymbol{h}$ is a height of the lifted ball. If the rod length is equal to $\boldsymbol{l}$ then we can write (according to Figure 5.1)

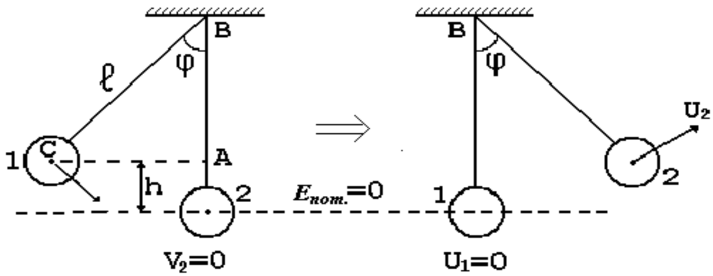

Figure 5.1

$$\frac{l-h}{l} = \cos\varphi$$

$$h = l\cdot(1-\cos\varphi) = 2l\cdot\sin^2\frac{\varphi}{2}$$

$$V = 2\sqrt{gl}\cdot\sin\frac{\varphi}{2}$$

$$F = \frac{2m\sqrt{gl}\cdot\sin\dfrac{\varphi}{2}}{\tau}\ . \qquad (5.2)$$

Here $\boldsymbol{F}$ is interaction force. You have to count the impact force in this laboratory work. To do this it is necessary to determine numbers $\boldsymbol{N}$ and numbers $\boldsymbol{N_0}$ of electric pulses at the beginning. For that you have to

1) switch on the device ПС02-2М;
2) wait for 5 - 7 minutes to warm up the device;
3) press the key "M" and "f";
4) connect the balls together (with you hand) and press them to each other for good electric contact and press the key "СБРОС" and then "ПУСК";

5) look at the indicator and write down the numbers of pulses passing during 1 second - N_0 ;
6) repeat this measurement process four times (you must have five measurements of value N_0).
Then you have to obtain the value of N. To do that you have to:
1) press the key "100";
2) deviate one of the balls at the angle $\varphi = 10^0$;
3) release the ball and press the key "ПУСК" simultaneously;
4) press the key "СТОП" after the first balls impact;
5) write out the value N from the indicator;
6) repeat your measurement process four times (you must have five measurements of N).

5.4 Experimental part

1. Measure the number of pulses N_0 by the device ПС02-2М as in was shown above.
2. Measure the number of pulses N the same way ($\varphi = 10^0$).
3. Fill in the table

Table 5.1

n	N_0	ΔN_0	$(\Delta N_0)^2$	N	ΔN	τ, s	v, m/s	F, N
1								
2								
3								
4								
5								

4. Calculate mean impact time by the formula (5.1) using $\overline{N}$ and $\overline{N}_0$.
5. Calculate mean impact force F by the formula (5.2) using $m = 0.6$ kg, $l = 0.72$ m, $\varphi = 10$ and obtained above.
6. Calculate absolute and relative error for τ and F.
7. Draw the conclusion.

Control questions

1. Formulate the first Newton's law.
2. Formulate the second Newton's law.
3. Formulate the third Newton's law and the law of conservation of momentum (impulse).

4. What system is isolated (or closed)?
5. Write the relation between a force and an impulse.
6. Formulate the law of conservation of mechanical energy.
7. Give the determination of perfectly elastic and perfectly inelastic impact.
8. Write the laws of conservation for the impact of two balls.

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6 LABORATORY WORK № 4.2. INELASTIC IMPACT OF BODIES

THE AIM: to study the laws of conservation of mechanical energy and impulse.
INSTRUMENTATION AND ACCESSORIES: two metallic cylinders suspended to the light rods, angle scale.

6.1 Short theory of inelastic impact

The impact is the process of final alternation of velocities of bodies in a comparative short time. During perfectly inelastic impact when the forms and the sizes of bodies obtained during deformation remain after the stop of action of forces, perfectly plastic deformation takes place. The kinetic energy of the bodies motion partially transforms into heat and partially into kinetic energy. The system is closed (the work of the external forces is equal to zero) and dissipative. In such systems the law of conservation of the impulse accomplishes, but the law of conservation of mechanical energy doesn't, because the part of energy converts into non-mechanical energy-heat. But the law of conservation of all kinds of energy for closed systems accomplishes. Let's examine inelastic central impact (fig.6.1).

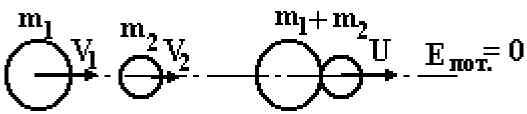

Figure 6.1

The bodies move as whole body after the impact, it means that the velocity ***U*** of both bodies is the same. Let's write down the equation of conservation of impulse and energy, taking into consideration that during the plastic deformation educes heat ***Q***:

$$m_1\upsilon_1 + m_2\upsilon_2 = (m_1 + m_2)\cdot U, \qquad (6.1)$$

$$\frac{m_1\upsilon_1^2}{2} + \frac{m_2\upsilon_2^2}{2} = \frac{(m_1 + m_2)U^2}{2} + Q\ . \qquad (6.2)$$

If we know masses of the bodies m_1 and m_2 and velocities $\boldsymbol{V_1}$ and $\boldsymbol{V_2}$ before the impact we can find the velocity ***U*** after the impact and the amount of heat ***Q***.

$$U = \frac{m_1\upsilon_1 + m_2\upsilon_2}{m_1 + m_2}, \tag{6.3}$$

$$Q = \frac{m_1\upsilon_1^2}{2} + \frac{m_2\upsilon_2^2}{2} - \frac{(m_1 + m_2)U^2}{2}. \tag{6.4}$$

Consequence: If the masses of the bodies are the same and one of the bodies, for example the second is not moving(stable), then after the impact U=0,5v, it means that the velocity is twice reduced and the half of kinetic energy transfers into heat.

$$Q = \frac{m\upsilon_1^2}{2} - \frac{(2m)U^2}{2} = \frac{m\upsilon_1^2}{2} - \frac{(2m)}{2}\cdot\left(\frac{\upsilon_1}{2}\right)^2 = \frac{1}{2}\cdot\frac{m\upsilon_1^2}{2}. \tag{6.5}$$

In this work we examined inelastic impact of two bodies with the same mass which are suspended to the rods (fig.6.2). Inclination angles of the rods are measured by the scale. The masses of the bodies M , the rods m and the lengths of the rods L are the same.

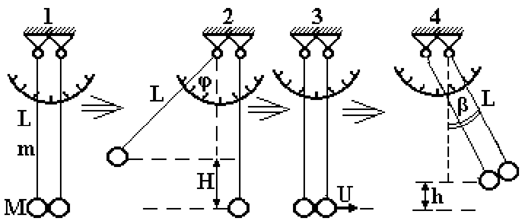

Figure 6.2

During the inclination of the rod with the weight to the angle ф, the centre of the body weight lifts for ***H***, and the centre of the weight of the rod for ***H/2.*** Their potential energy increases for such value

$$\Delta E_{\text{пот}} = MgH + 0{,}5mgH = (M + 0{,}5m)gH(1 - \cos\varphi) = 2(M + 0{,}5m)gH\sin^2\frac{\varphi}{2}. \tag{6.6}$$

At the moment when a body passes low position, that means before the impact this potential energy in accordance to the law of conservation of mechanical energy (if don’t count the resistance of the air and the force of friction suspended), transforms into the kinetic energy of rotating body before the impact

$$E_O = \frac{1}{2}J\omega^2 = \frac{1}{2}\left(ML^2 + \frac{1}{3}mL^2\right)\cdot\left(\frac{\upsilon}{L}\right)^2 = \frac{1}{2}\left(M + \frac{1}{3}m\right)\upsilon^2 \cdot \qquad (6.7)$$

Where ***J*** is the sum of moments of inertia of the weight ML^2 (as a material point) and of the rod ***⅓mL*** concerning the point of suspension; ***ω*** is the angular velocity of rotation; ***v*** is the velocity of the weight before the impact.

After comparing the right parts of equations (6.6) and (6.7), we can find the velocity depending on the inclination angle

$$\upsilon = 2\cdot\sin\frac{\varphi}{2}\sqrt{\frac{M + \frac{1}{2}m}{M + \frac{1}{3}m}\cdot g\cdot H}\,. \qquad (6.8)$$

After the impact the bodies move as whole body. So to find the velocity ***U*** and the kinetic energy E after the impact, in formulas (6.7) and (6.8) we should change ***M*** and ***m*** correspondingly into **2M** and ***2m***, and the angle ***φ*** into inclination angle *β* after the impact

$$U = 2\cdot\sin\frac{\beta}{2}\sqrt{\frac{2M + m}{2M + \frac{2}{3}m}}\cdot g\cdot H = \upsilon\frac{\sin\frac{\beta}{2}}{\sin\frac{\varphi}{2}}\,. \qquad (6.9)$$

$$E = \frac{1}{2}\left(2M + \frac{1}{3}2m\right)U^2 \cdot \qquad (6.10)$$

The relative losses of mechanical energy for heat from equations (6.7) ÷ (6.10)

$$\frac{Q}{E_O} = \frac{E_O - E}{E_O} = 1 - \frac{E}{E_O} = 1 - \frac{2U^2}{\upsilon^2} = 1 - \frac{2\sin^2\frac{\beta}{2}}{\sin^2\frac{\varphi}{2}}\,. \qquad (6.11)$$

6.2 The sequence of performing the work

1. Count the initial inclination angle by formula φ**=15+3*N*** in degrees for the first half of students or **φ=3*N*** for the second half of students. ***N*** is the number of the subgroup of students.
2. For supplying an inelastic character of the impact you should form little hill made of plasticine on the interacting surfaces of the bodies.

3. Incline one of the rods to the counted angle ϕ and release it. Fix the inclination angle B after the impact by a scale.
4. Repeat 3d item 4 times (in the whole 5 times), watching that after the impact the bodies stick together with the help of plasticine. Fill in the table with the results of measurements.
5. Calculate the values filled in the table, and the error β of the measurement of angle β.
6. Calculate the relative loss of mechanical energy by formula (6.11), obtained experimentally.
7. Compare the values $\sin(\varphi/2)$ and $2\sin(\beta/2)$. If the law of conservation of impulse accomplishes then according to the formula (6.9) and consequence, the values of **sin** must be the same.
8. Make a conclusion about the accomplishing of the laws of conservation of the impulse and mechanical energy.

Table 6.1

№	φ	βi	$\Delta\beta_i$	$\Delta\beta_i^2$	$\sin\frac{\varphi}{2}$	$\sin\frac{\overline{\beta}}{2}$	$\sin^2\frac{\varphi}{2}$	$\sin^2\frac{\overline{\beta}}{2}$
		$\overline{\beta} =$		$\sum\Delta\beta_i^2 =$				

Control questions

1. What is the impact?
2. What kind of impact is called perfectly plastic?
3. What kinds of systems are called closed?
4. Formulate the law of conservation of the impulse.
5. Formulate the law of conservation of mechanical energy.

6. Write down the law of conservation of the impulse for central perfectly inelastic impact of the balls.
7. Write down the law of conservation of mechanical energy for central perfectly inelastic impact of the balls.
8. Deduce a formula for determination the velocities of balls after perfectly inelastic impact.

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Translator: S.P. Lushchin, associate professor, candidate of physical and mathematical sciences.
Reviewer: S.V. Loskutov, professor, doctor of physical and mathematical sciences.
Approved by the chair of physics. Protocol № 3 from 01.12.2008 .

7 LABORATORY WORK № 5. STUDY OF THE FUNDAMENTAL EQUATION OF THE ROTATIONAL MOTION DYNAMICS

THE AIM is to apply a dynamic method to the determination moment of inertia and to study the basic low of rotational motion.
INSTRUMENTATION AND ACCESSORIES: cross-shaped pendulum, seconds counter, set of loads.

7.1 Description of installation and measuring method

The cross-shaped pendulum is Oberbeck's pendulum. It consist of two sheaves with radii are r_1 and r_2, and four crosswise shafts. Four loads with equal masses m are able to move along shafts. A thread is wound on one of the sheaves. A load $P = mg$ is fasten to the other end of the thread. When the load P falls, the thread unwinds. A mechanical brake is possible to operate the motion of the load from the start to the end of its motion.

The displacement of the load can be measured by means of on indicator panel. It is not difficult to show that the acceleration of the load is

$$a = \frac{2h}{t^2} \;,$$

where ***h*** is the distance of the falling load; ***t*** is the time of the falling load.

The load is allowed to fall under the action of its own weight. It equals mg. The line acceleration of the point at the sheaf surface is equal to the load acceleration. Then angular acceleration can be represented as

$$\varepsilon = \frac{a}{r} = \frac{2h}{rt^2}, \qquad (7.1)$$

where ***r*** is radius of the sheaf. According to the second Newton's law

$$mg - N = ma \;,$$

where ***N*** is pull of the thread. Then, pull of the thread is given by

$$N = m(g - a) \;.$$

Moment of force at the cross-shaped pendulum may be expressed as

$$M = m(g - a)r \;.$$

In our experiment conditions usually $a \ll g$. Then

$$M = mgr \;. \qquad (7.2)$$

The fundamental equation of motion for a rotating body is as follows

$$M = I \cdot \varepsilon, \tag{7.3}$$

where ***I*** is the moment of inertia of the pendulum; ***ε*** is the angular acceleration of the pendulum. From the formulas (7.2) and (7.3) it follows that

$$\mathrm{I} = \frac{\mathrm{mgr}}{\varepsilon}. \tag{7.4}$$

Taking (7.1) into consideration of formula (7.4) one may receive

$$\mathrm{I} = \frac{\mathrm{mg}}{2\mathrm{h}} \cdot \mathrm{r}^2 \mathrm{t}^2 \quad . \tag{7.5}$$

If ***I = const***, then

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{\mathrm{M}_1}{\mathrm{M}_2}.$$

If ***M = const***, then

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{\mathrm{I}_2}{\mathrm{I}_1}.$$

Moment of inertia of the cross-shaped pendulum consists of the moment of inertia of the cross-shaped $\boldsymbol{I_l}$ (as is shown on the device) and moment of inertia of four loads at the shafts

$$I_1 = 4mR^2, \tag{7.6}$$

where ***m*** is the mean mass; ***R*** is the distance between the axis of revolution and the centre of gravity loads m.

7.2 Task 5.1

THE AIM is to determine the angular accelerations and moments of forces of the pendulum when values of falling loads are different and when moment of inertia is constant.

1. Put down the data of measurements in table 7.1.

Table 7.1

№	t, s	m, kg	r, m	h, m	ε, s^{-2}	M, N·m	Note
1							The measurement is done with the system of fife loads
2							
3							
4							
5							
6							The load is decreased by one part.
7							The load is decreased by two parts.
8							The load is decreased by three parts.
9							The load is decreased by four parts.

2. Calculate ***Δε/ε***. Put down the results of calculations in table 7.2.

Table 7.2

N	t_i, s	Δt_i,s	Δt_i^2, s^2	Half-width of the trust interval				Δε/ε
				Δt, s	Δh, m	Δr, m	Δε, s^{-2}	
1								
2								
3								
4								
5								

$\Sigma t_i =$ $\Sigma \Delta t_i^2 =$

$\bar{t} =$

3. Put ***M*** versus ε on the graph.

4. Determine the moment of the friction forces and moment of inertia on the graph.
5. Make analysis of the experiment results.

7.3 Task 5.2

THE AIM is to determine the angular acceleration and moments of forces of the pendulum with different values of the sheaves radius and when moment of inertia is constant.

1. Put down the data of measurements in table 7.3.

Table 7.3

№	t_1, s	r, m	m, kg	h, m	ε, s^{-2}	M, N·m	Note
1							The measurements are made when a thread is wound on big sheaf
2							
3							
4							
5							
6							The measurements are made on other four sheaves
7							
8							
9							

2. For the first five measurements use average time $\boldsymbol{t}$, when you calculate $\boldsymbol{\varepsilon}$.
3. Calculate $\frac{\Delta M}{M}$ for one measurement. Calculate the half-width of the confidence interval for $\boldsymbol{r}$ to use the main errors of measurement, $\boldsymbol{m_0}$ and $\boldsymbol{g}$ are table values.
4. Calculate the half-width of the confidence interval for $\boldsymbol{t}$ using the first five measurements.
5. Put down the data of measurements in the table 7.4.

Table 7.4

№	t_i s	Δt_i, s	Δt_i^2, s^2	Half-width of the trust interval					ΔM/M
				Δt, s	Δr, m	Δm, kg	Δg, m/s^2	ΔM, N·m	
1									
2									
3									
4									
5									
$\bar{t}$ =					$\Sigma \Delta t_i^2$=				

6. Put ***M*** versus ***ε*** on the graph.
7. Determine moment of inertia on the graph.
8. Make analysis of the experiment results.

7.4 Task 5.3

THE AIM is to determine moment of inertia of four loads at the shafts with dynamics and theoretical methods.
1. Put the data of measurements in the table 7.5.

Table 7.5

№	t, s	$\bar{t}$, s	m_0, kg	r, m	h, m	R, m	$\overline{m}$, g	I_1, $kg \cdot m^2$	I_0, $kg \cdot m^2$	I_0^1, $g \cdot m^2$
1										
2										
3										
4										
5										

2. Determine the moment of inertia of four loads at the shafts with the dynamics method.

$$I_в = k\left(I - I_0\right),$$

where $\boldsymbol{I_0}$ is the moment of inertia of cross-shaped pendulum ($\boldsymbol{I_0} = 4{,}15 \cdot 10^{-2}$ $\kappa g \cdot m^2$); $\boldsymbol{k}$ is a coefficient, it takes into consideration the mean forces of friction and errors of the time measurements (k = 1.1).

3. Calculate the moment of inertia of four loads at the shafts by the formula

$$I_e^1 = 4\bar{m}R^2,$$

where $\bar{m}$ is the mean mass of four loads; $\boldsymbol{R}$ is distance between the axis of rotation and the centre of load's gravity.

4. Calculate $\boldsymbol{\Delta I/I}$ as an error of indirect measurement. Calculate the half-width of the confidence interval for r and h as a direct measurement errors, m and g are the table values. Calculate the half-width of the confidence interval of t as five direct measurements error.

5. Put the results of calculation in table 7.6.

Table 7.6

N	t_i, s	Δt_i, s	Δt_i^2, s^2							$\Delta I/I$
				Δt, s	Δl, m	Δr, m	Δm, kg	Δg, m/s^2	ΔI, $kg \cdot m^2$	
1										
2										
3										
4										
5										
	$\Sigma t_i =$ $\bar{t} =$		$\Sigma \Delta t_i^2 =$							

6. Analyse the experimental results and draw the conclusion.

$m_0 = 0{,}5$ kg; m(I) = 0,592 kg; m(II) = 0,59 kg; m(III) = 0,575 kg; m(IV) = 0,592 kg; $I_0 = 4{,}5 \cdot 10^{-2}$ $kg \cdot m^2$

7.5 Task 5.4

THE AIM is to determine the angular accelerations and moments of inertia of the pendulum when the load masses at the shafts are changed and the moment of force is constant.

1. Put down the data of measurements in table 7.7.

Table 7.7

№	T, s	The middle mass of the load $\overline{m}$, kg	r, m	h, m	R, m	ε_0, s^{-2}	I, kg·m^2	1/I, kg^{-1}·m^{-2}	Note
1									Measurement with the first set of loads
2									
3									
4									
5									
6									…with the second set of loads.
7									…with the third set of loads.
8									…with the fourth set of loads.
9									…with the set of loads.

2. Calculate angular acceleration defined by

$$\varepsilon = \frac{a}{r} = \frac{2h}{rt^2}.$$

3. Calculate moments of inertia given by

$$I = I_0 + 4\overline{m}R^2,$$

where $\boldsymbol{I_0}$ is the moment of inertia of the pendulum without loads ($I_0 = 4{,}6 \cdot 10^{-2}$ кg/m^2); $\boldsymbol{m}$ is the mean mass of four loads at the shafts; $\boldsymbol{R}$ is the distance between the axis of revolution and the centre if gravity loads.

4. Calculate $\Delta\varepsilon/\varepsilon$ and $\boldsymbol{\Delta\varepsilon}$ for five measurements. Calculate the half-width of the confidence interval for r and h using the main errors of measure-

ments. Calculate the half-width of the trust interval for t using five measurements.

5. Results of calculation carry in the table 7.8.

Table 7.8

№	t_i, s	Δt, s	Δt_i^2, s^2	Half-width of the trust interval				$\frac{\Delta\varepsilon}{\varepsilon}$
				Δt, s	Δh, m	Δr, m	$\Delta\varepsilon$, s^{-2}	
1								
2								
3								
4								
5								

$\sum t_i =$ $\sum\Delta t_i^2 =$ $\bar{t} =$

6. Make analysis of the experiment results.

7.6 Task 5.5

THE AIM is to determine the angular accelerations and moments of inertia of the pendulum with changed distance of the loads at the shafts and a moment of force is constant.

1. Measure ***t*** and ***h*** for five different distances of the loads at the shafts.
2. Put down the data of measurements in table 7.9.

Table 7.9

№	r, m	h, m	$\bar{m}$, kg	t, s	R, m	R^2, m^2	ε, s^{-2}	I, $kg\cdot m^2$	Note
1									The measurementon the arrangement of the loads the first position.
2									
3									
4									
5									
6									The measurement on the next position.
7									
8									
9									

3. Calculate angular acceleration defined by

$$\varepsilon = \frac{2h}{rt^2}\cdot$$

4. Calculate moment of inertia given by

$$I = I_0 + 4\overline{m}R^2,$$

where I_0 is the moment of inertia of the pendulum without loads ($I_0 = (3{,}95 \mp 0{,}12)\cdot 10^{-2}$) kg m^2; ***m*** is the mean mass of four loads at the shafts; ***R*** is the distance between the axis of revolution and centre of gravity loads.

5. Calculate ***ΔI*** and $\frac{\Delta I}{I}$ for one measurement. Calculate the half-width of the confidence interval for ***R*** to use main errors of measurements, and ***m*** is the table values; $\Delta I_0 =$

6. Put down the results of calculations in table 7.10.

Table 7.10

№	t_i, s	Δt_i. s	Δt_i^2, s^2	Half-width of the trust interval					$\frac{\Delta I}{I}$
				Δt, s	ΔR, m	Δm, kg	ΔI_0, kg·m^2	ΔI, kg·m^2	
1									
2									
3									
4									
5									

$\sum t_i =$ $\sum \Delta t_i^2 =$ $\overline{t} =$

7. Put ***I*** versus ***R²*** on the graph.
8. Put ***I*** versus ***ε*** on the graph.
9. Make analysis of the experimental results.

7.7 Task 5.6

THE AIM is to determine moment of inertia of the pendulum with dynamics and theoretical methods.

1. Put down the data of measurement in table 7.11.

Table 7.11

№	t,s	$\bar{t}$, s	m_0. kg	r, m	h, m	R, m	$\overline{m}$, kg	l, m	R_1, m	I, kg·m^2	I$'$, kg·m^2
1											
2											
3											
4											
5											

2. Determine the moment of inertia of the pendulum by with the dynamics method

$$I = k\frac{m_0 g r^2 t^2}{2h}$$

where k is the correct coefficient, it takes into consideration the mean forces of friction and errors of the time measurement (k=.3); m is the mass of the falling load; r is radius of the sheaf; t is the time of the load fall.
3. Determine the moment of inertia of the pendulum with the theoretical method

$$I' = 4\overline{m}R^2 + 2\frac{1}{12}m_1 l^2 + m_2 R_1^2,$$

where $\overline{m}$ is the mean mass of four loads at the shafts; R is the distance between the axis of revolution and the centre of gravity loads; m is the mass of one shaft; m is the mass of the hoop; R_1 is the radius of the hoop.
4. Calculate $\frac{\Delta I}{I}$. Calculate the half – width of the confidence interval for r and h using the main errors of measurements and m and g are the table values. Calculate the half-width of the trust interval for t using five measurements.
5. Put down the results of calculation in table 7.12.
6. Compare I and I$'$. Make analysis of the experiment results.

Table 7.12

№	t_i, s	Δt_i. s	Δt_i^2, s^2	Half-width of the trust interval					$\frac{\Delta I}{I}$
				Δt, s	Δr, m	Δm_0, kg	Δg, m/s^2	Δ I, $kg \cdot m^2$	
1									
2									
3									
4									
5									

$\sum t_i =$ $\sum \Delta t_i^2 =$ $\bar{t} =$

Control questions

1. Obtain a relationship between linear and angular velocity.
2. Obtain a kinetic energy of rotation.
3. Obtain a formula for moment of inertia if the entire disk.
4. How is a moment of force determined?
5. Obtain the fundamental equation of rotation.
6. Make a comparison between the formulas of motion of a particle and derive the laws for the rotation of a solid body.
7. Obtain the law of conservation of momentum for the rotation motion.
8. What is a gyroscope?

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Translator: S.V. Loskutov, professor, doctor of physical and mathematical sciences.

Reviewer: S.P. Lushchin, the reader, candidate of physical and mathematical sciences.
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8 LABORATORY WORK № 6. VERIFICATION OF THE HUYGENS-STEINER (PARALLEL AXIS) THEOREM

***THE AIM*:** to calculate the moment of inertia of cylinder, which is revolved in relation to an axis which does not pass through its center of mass, experimentally and on the theorem of Steiner.

***INSTRUMENTATION AND ACCESSORIES*:** apparatus on three of thread suspension, 2 cylinders, vernier caliper.

***Task to work*:**

1. To expect the moment of inertia of empty disk I_{disk} .
2. To calculate the moment of inertia of the system I_1, which consists of disk and two cylinders.
3. To calculate the moment of inertia of cylinder I' and I experimentally and by the theorem of Steiner.
4. To make sure of justice of theorem of Steiner.

8.1 Theory

Moment of inertia, also called **mass moment of inertia** or the **angular mass** is a measure of an object's resistance to changes in its rotation rate. It is the rotational analog of mass. That is, it is the inertia of a rigid rotating body with respect to its rotation. The moment of inertia plays much the same role in rotational dynamics as mass does in basic dynamics.

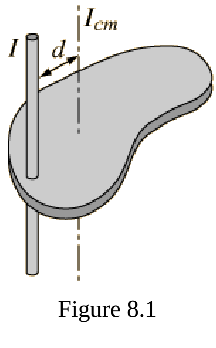


Figure 8.1

The moment of inertia depends on mass, form and sizes of bodies, distribution of mass in relation to the axis of rotation, choice of axis of rotation. The moment of inertia of an object about a given axis describes how difficult it is to change its angular motion about that axis.

The moment of inertia is always defined with reference to a particular axis of rotation - often a symmetry axis, but it can be any axis, even one that is outside the body.

The moment of inertia $\boldsymbol{I_{cm}}$ of any object about an axis through its center of mass is the minimum moment of inertia for an axis in that direction in space. The moment of inertia $\boldsymbol{I}$ about any axis parallel to that axis through the center of mass is given by

$$I = I_{cm} + md^2 .$$

8.2 Description of device and method of measuring

In this work apparatus is used on three of thread suspension which allows finding experimentally the moments of inertia of simple bodies. A apparatus consists of disk (2), which is revolved in rotatory motion by a drive (6). The handle of drive turns (5) and spring thread (8) intertwines. Than it untwists and passes the impulse of rotatory motion to an overhead disk (7). Metallic filaments (4) a few bend over, and the mass center of the system is displaced along the axis of rotation. The moment of forces of resiliency tries to turn a disk in the state of equilibrium. A lower disk accomplishes rotators oscillations the period of which depends on a moment inertia of the system. As a bar center of disk is displaced, his potential energy changes. Using the law of conservation of mechanical energy, will get a formula which allows to define the moment of inertia of lower disk:

$$I = \frac{(m_D \cdot gRr)}{4\pi^2 L} \cdot T_D^2 , \tag{8.1}$$

where: $\boldsymbol{m_D}$ – mass of lower disk, $\boldsymbol{g}$ - acceleration of the free falling, $\boldsymbol{R}$ - distance from the center of disk to the points in which threads are fastened to it, $\boldsymbol{r}$ - radius of lower disk, $\boldsymbol{L}$ – length of threads of suspension, $\boldsymbol{T}$ – period of oscillations

$$T = \tau / k , \tag{8.2}$$

where: $\boldsymbol{\tau}$ – time of oscillations, $\boldsymbol{k}$ – amount of oscillations.

A formula (8.1) enables to define the moment of disk inertia with the bodies placed on him. In obedience to the theorem of Steiner

$$I' = I_0 + ma^2 , \tag{8.3}$$

where: $\boldsymbol{I_0}$ – moment of inertia of cylinder in relation to an axis 1 (fig. 8.2a), $\boldsymbol{I}$ - moment of inertia of cylinder in relation to an axis 2 (fig. 8.2б), $\boldsymbol{m}$ - mass of cylinder, a - distance between axes (fig. 8.2б).

It is possible to calculate the moment of inertia of cylinder in relation to an axis 2 experimentally too:

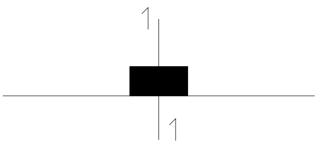
$$I' = \frac{(I_1 - I_D)}{2} \tag{8.4}$$

where: $\boldsymbol{I_1}$ – moment of inertia of the system, which consists of disk and two cylinders, placed on identical distances $\boldsymbol{a}$ from the axis of rotation (fig.8. 2б), $\boldsymbol{I_D}$ – moment of inertia of empty disk (fig. 8.2в). The moment of inertia of cylinder I_0 is determined by the formula:

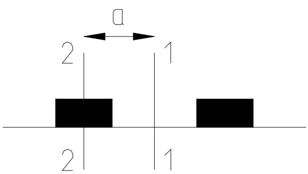
$$I_0 = \frac{1}{2} m r_c^2 \tag{8.5}$$

where: $\boldsymbol{r_c}$ – radius of cylinder. Putting I_0 in (8.3) and, meaning that $r_c = d/2$, will get

$$I_0 = \frac{1}{8} m d^2 + m a^2 . \tag{8.6}$$



(a)



(б)

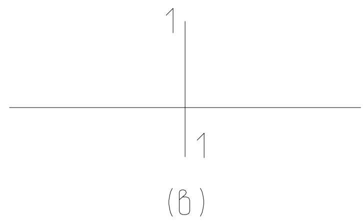


Figure 8.2

8.3 Procedure and analysis

1. Reject unloaded disk on 5 small limb's divisions.
2. Measure time t_D of 10 oscillations.
3. Repeat that measurements already two times.
4. Put two cylinders in the disk on equal distances from an axis of rotation.
5. Measure time t of 10 disk's oscillations with two cylinders.
6. Measure once distance a and cylinder's diameter d.
7. Measure oscillations period of unloaded disk T_D and oscillations period with two cylinders T (8.2), using values t_D and t .
8. Calculate unloaded disk's moment inertia I_D (1) using values: m_D = 2 kg, R = 0,13 m, r =5,5×10^{-2} m , L = 2,2 m.
9. Calculate with two cylinders disk's moment of inertia I_1 (8.1), using instead of m_D value $m_D + 2\overline{m}$. The mass m is shown on cylinders.
10. Measure cylinder's moment of inertia I' concerning an axis by experimental method's means (8.4).
11. Calculate cylinder's moment of inertia I concerning an axis 2 according to Steiner's theorem (8.6). Data of measurements and calculations put in the table.
12. Compare received results I' and I , and draw a conclusion about validity of the Steiner's theorem.

Table 8.1

№	t_D s	t s	T_D s	T	a м	d м	I_D $kg\ m^2$	I_1 $kg\ m^2$	I' $kg\ m^2$	I $kg\ m^2$

Control questions

1. Define parameters of rotary movement: the moment of force, inertia, an impulse, angular speed, angular acceleration.
2. Write down work's calculation formulas: kinetic energy of rotary movement.
3. Deduce the basic equation dynamics of rotary movement.
4. Write down the law: preservation moment of an impulse.
5. Deduce parities for kinetic energy of rotary movement.
6. Write down Steiner's theorem.

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Approved by the chair of physics. Protocol № 3 from 01.12.2008 .

9 LABORATORY WORK № 7. DETERMINATION OF THE RATIO OF THE SPECIFIC HEAT Cp/Cv FOR GASES

THE AIM: To determine a ratio of the specific heat at constant pressure to specific heat at constant volume

INSTRUMENTATION AND ACCESSORIES: the device for a ratio of specific heat C_p/C_v determination, manometer.

9.1 The description of the device and method of measurements

The device (Fig. 9.1) consists of a glass sphere (1) of 12 liters volume, goffered tube (2), rod (3), handle of the spring valve (4), spring valve (5), stopper (6), handle of a rod (7), water manometer (8).

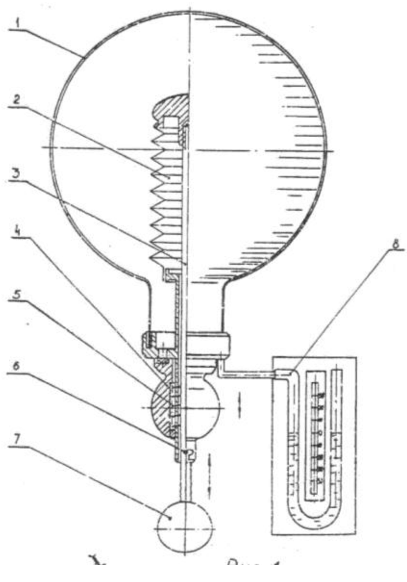

Figure 9.1

The sphere can incorporate to an atmosphere with the help of the spring valve. It is possible to increase or to reduce volume of gas in a sphere it is possible at the expense of a stretching or compression goffered tube at lowering or rise of the handle of a rod. The stopper is used for fixation of a rod in the top position. The difference between the pressure of air inside and outside of the sphere is measured by water manometer.

If to move a rod downwards up to the stop, and then quickly delay downwards spring valve, the pressure of air inside a sphere becomes equal to atmospheric pressure outside of a sphere. At movement of a rod upwards up to a stop there is action of force on air in a sphere. Thus the external force makes above air some certain work. As a result the internal energy of air in a sphere is increased, and its temperature becomes above room one.

The compression of air occurs as adiabatic process. During some time (approximately two minutes) occur reductions of temperature of air in a sphere up to a room temperature.

Thus the difference between levels of a liquid in manometer is decreased. It is possible to consider reduction of temperature of air in a sphere as the process at a constant volume.

If to pull down handle of the spring valve within 0,5 seconds, the part of air will exhaust for an atmosphere. Thus, air, which has remained in a sphere, does some work on expansion of gas.

Thus, the internal energy of air which has stayed in a sphere, decreases, and its temperature becomes lower than a room temperature, and its pressure will be equal to the atmospheric pressure. It is possible to consider expansion of air as adiabatic process. Temperature of air in a sphere will be raised up to a room temperature in two minutes. As a result, the pressure in a sphere will increase, and the difference of levels of a liquid in manometer will increase.

9.2 Experimental part

1. Pull down to stopper the handle of a rod (7).
2. Pull down to stopper the handle of the spring valve (4) till the levels of a liquid in manometer become equal, and release the handle.
3. Lift the handle of a rod (7) and fix by its stopper (6).
4. In two minutes you have to write down value of a difference of levels of a liquid in manometer in your experimental table - h_1.
5. Pull down handle of the spring valve (4) and keep it in this position within 0.5 seconds.
6. In two minutes you have to write down value of a difference of levels of a liquid in manometer into your experimental table - h_2 .

7. Repeat researches on $1 \div 6$ two times more and write down its in table 9.1.
8. Calculate the experimental value of ratio C_p/C_v by means of the formula

$$\gamma = \frac{h_1}{h_1 - h_2}.$$

9. Calculate a relative error by means of the formula:

$$E = \frac{\Delta\gamma}{\gamma} = \sqrt{\left(\frac{\Delta h_1}{h_1}\right)^2 + \left(\frac{\Delta h_1}{h_1 - h_2}\right)^2 + \left(\frac{\Delta h_2}{h_1 - h_2}\right)^2}$$

Table 9.1

№	h_1, mm	H_2, mm	γ	$\bar{\gamma}$
1				
2				
3				

You have to take the magnitudes of $\boldsymbol{h_1}$ and $\boldsymbol{h_2}$ from any of the three carried out experiments, and find a confidential interval under the formula for unitary measurement. For a scale manometer an error is equal to 1 mm and error of readings is equal to 0.5 mm.
10. Determine a confidential interval by means of the formula

$$\Delta\gamma = E\bar{\gamma}.$$

11. Calculate a magnitude C_p/C_v for air by means of the formula

$$\gamma = \frac{i+2}{i}.$$

For two-atomic gas $\boldsymbol{i} = 5$, for three-atomic gas $\boldsymbol{i} = 6$.

Compare the ratio $\boldsymbol{C_p/C_v}$ to the magnitude, received in experiment.

Control questions

1. List processes occurring in ideal gases. Explain difference between them.
2. Formulate and write down the first law of thermodynamics.
3. Write down the first law of thermodynamics for each of isoprocess.
4. Give definition of a number of degrees of freedom of gas molecules.

5. Write down the formula to calculate the average value of kinetic energy of translation motion of a molecule with use of number of degrees of freedom .
6. What average energy corresponds to one degree of freedom of a molecule of gas?
7. By what formula is the internal energy of ideal gas determined?
8. Give definition of heat capacity of a body and specific heat.
9. Why is specific heat at constant pressure more then specific heat at constant volume?
10. How are C_p and C_v connected to number of degrees of freedom?
11. Write down the formula to calculate the ratio of C_p/C_v with using of number of degrees of freedom.

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10 LABOR SAFETY REGULATION №62 DURING WORKING IN PHYSICS LABORATORY

10.1 General provisions

10.1.1 People who are allowed to work in the lab:
- members of the department who know their functional responsibilities and have an access to the independent work;
- students who have learnt behavior rules in the lab, who know methods of the performance of the laboratory work and who are well instructed.

10.1.2 Briefing is performed by the member of the department. Every student must confirm his knowledge of the briefing with his personal signature in journal 'Labor safety regulation of students'
10.1.3 Teacher permits students to work in the lab after checking of their knowledge level of the methods of laboratory works performing.

10.2 Safety requirements before starting work

10.2.1 Only instruments in good working condition are used.
10.2.2 Before starting work teacher must check the working condition of the devices and then permit to work.
10.2.3 People who don't take part in the laboratory work don't have an access to the lab.

10.3 Safety requirements during laboratory work

10.3.1 It's not allowed to turn on or turn off the sources of the electrical or light energy without permission of the teacher.
10.3.2 It's not allowed to turn different screws, press any buttons, switches without permission of the teacher.
10.3.3 Students must immediately inform the teacher about all shortcomings of the devices

10.4 Safety requirements after finishing the work

10.4.1Before finishing the work student must consecutively turn off all devices.

10.4.2 Student must check by sight serviceability of the devices. It’s necessary to remember that student is responsible for the broken-down devices.

10.5 Safety requirements in case of emergencies

10.5.1 Student must:
- stop working;
- turn all devices off;
- inform teacher about what has happened in the lab.

10.5.2 In case of the fire student must begin to extinguish a fire with available means.

10.5.3 Teacher must call the number 9-101 and notify about accident.

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