MINISTRY of EDUCATION AND SCIENCE of UKRAINE

O. M. BEKETOV NATIONAL UNIVERCITY
OF URBUN ECONOMY IN KHARKIV

Methodical guidelines
for performance laboratory works
on the subjects

"PHYSICS" and "GENERAL PHYSICS"

part 1 "MECHANICS"

*(for1 st-year of full-time and part-time students education level "bachelor"
all specialties)*

Khakiv – O. M. Beketov – 2019

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CONTENT

ENTRY

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

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

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

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

1 SUBSTANTIVE PROVISIONS OF THEORY OF THE MEASURING OF ERRORS

Measuring it is determining of values of physical quantity by an experience way by means of the special technical equipments and its comparing to other homogeneous quantity that is taken for unit. It is distinguished two types of measuring of physical quantity – direct and indirect. In case of the direct measuring the values of physical quantity are founded directly by means of device. For example, the values of temperature and pressure are determined after the indications of thermometer and barometer accordingly. At the indirect measuring the values of physical quantity are determined on the basis of the direct measuring of others ones related to the wanted quantity by certain functional dependence. For example, the acceleration of the free falling bodies g, at using simple pendulum, can be found after

$$g = \frac{4\pi^2(l_2 - l_1)}{T_2^2 - T_1^2}$$

where the periods of oscillations *T*, and the lengths *l* are determined by the direct measuring.

Any measuring is accompanied by their errors that are: systematic, random and misses (flagrant errors).

Systematic errors are predefined by unchanging factors: the errors of facilities of measuring (instrumental ones) and error of the used method of measuring (methodical) behave to that. Systematic errors can be decreased, if to apply more perfect devices and methods of measuring.

Misses are predefined by the mal operations of experimenter or disrepair of measuring devices (instruments), that is why they are eliminated from the results of supervisions. Random errors are predefined by the difference of results at the repeated measuring. Their changes have statistical character and that is why its can be calculating by methods of chances theory.

1 1 PROCESSING OF RANDOM ERRORS IN DIRECT MEASUREMENTS

If as a result of repeated measurements of the physical quantity x, the values x1, x2, x3, … xn, are obtained, then the nearest to the true value is the arithmetic mean of this value , that is,

$$<x>=\frac{x_1+x_2+...+x_n}{n}=\frac{1}{n}\sum_{i=1}^{n}x_i. \qquad (1)$$

We will never know the true value of the physical quantity So, we assume $<x>=x_{true}$.

By finding the absolute errors of individual measurements, $|<x>-x_1|=\Delta x_1, |<x>-x_2|=\Delta x_2,\ldots |<x>-x_n|=\Delta x_n$, it can calculate the absolute error of the measurement result and give the result of measurements in the form

$$x=<x>\pm\Delta x. \qquad (2)$$

The ratio of absolute error to the true value of the measured value is called relative error δ, $\delta=\frac{\Delta x}{x}$. Relative error is expressed in percent, or in parts from the whole and that is a measure of measurement accuracy. Absolute error is a measure of the deviation of the mean value from the true value.

Let's consider two approaches that are often used to estimate the magnitude of known deviations: the method of arithmetic mean absolute error and the method of mean square error.

In the first method, as absolute error is took the average arithmetic absolute error, which is defined as the sum of individual absolute deviations, divided by the number of observations *n*

$$<\Delta x>=\frac{|\Delta x_1|+|\Delta x_2|+...+|\Delta x_n|}{n}=\frac{1}{n}\sum_{i=1}^{n}|\Delta x_i|. \qquad (3)$$

The end result is written as

$$x = < x > \pm < \Delta x >$$

This method of processing the results is too simplistic, since it does not contain information about the probability of finding x_{true} an interval $(< x > - < \Delta x >) < x_{true} < (< x > + < \Delta x >)$. However, it is widespread and convenient method.

In the method of mean squared error, the formulas (1) and (2) are also used, but, in accordance with the law of distribution (random variables) of the Student, the probability (reliability) of P is indicated that the true value is indeed in the above-mentioned interval. To estimate the value Δx, the **mean squared** (standard) **error** σ and Student's coefficient are used $\tau(P,n)$, i.e. $\Delta x = \sigma\,\tau(P,n)$. In this case, the value σ is determined by the formula (4):

$$\sigma = \sqrt{\frac{\Delta x_1^2 + \Delta x_2^2 + \dots + \Delta x_n^2}{n(n-1)}}, \qquad (4)$$

and the values of Student's coefficient are presented in the Table 1, at the intersection of the row corresponding to the number of observations, and the column corresponding to the given reliability.

Values of coefficient of Student's $\tau(P,n)$

n	P					
	0.5	0.8	0.9	0.95	0.975	0.99
2	1.00	3.08	6.31	12.71	31.82	63.66
3	0.82	1.89	2.92	4.30	6.97	9.93
4	0.77	1.64	2.35	3.18	4.54	5.84
5	0.74	1.53	2.13	2.78	3.75	4.60

10	0.70	1.37	1.83	2.26	2.82	3.25

The result is written down in a kind:

$$x = < x > \pm \sigma \cdot \tau \left(P, n \right), \tag{5}$$

The estimation of absolute error after a formula (5) is applicable at the small number of supervisions of n, as it takes place at implementation of laboratory works.

1.2 Treatment of Random Error Terms at the Indirect Measuring

In this case seeking quantity is a function one or a few the variables. On such conditions, knowing the errors of measuring of separate quantities, it is possible to define an error of result. As errors of measuring by comparison to measurable quantities small enough, it is possible to ignore their squares, and consequently for treatment of errors of the indirect measuring it is possible to use a differential calculation, in particular, the method of logarithmic differentiation. For determination of relative error in the case of the indirect measuring, in tune with this method it is necessary to do the following:

1) take natural logarithm from both parts of working formula;

2) differentiate logarithmic equality;

3) substitute all differentials in the got equalization by absolute errors, and minuses which appeared after the operations of taking the logarithm and differentiation change by pluses.

The last operation provides the maximal (maximum) error of result. Let us illustrate the rules of finding of absolute and relative errors at the indirect measuring on the example of determination of density of body of cylinder form. In this case a working formula is

$$\rho = \frac{m}{V} = \frac{m}{\pi\ r^2 h}\ , \tag{6}$$

where m = mass;

r = radius;

h = height of cylinder.

For finding of relative error $\delta_\rho = \frac{\Delta\rho}{\rho}$ will apply the afore-mentioned method of logarithmic differentiation. For this purpose at first take logarithm of expression (6):

$$\ln\rho = \ln m - \ln\pi - 2\ln r - \ln h\ . \tag{7}$$

In subsequent, differentiating (7), will get:

$$\frac{d\rho}{\rho} = \frac{dm}{m} - 2\frac{dr}{r} - \frac{d\ h}{h}$$

Replacing minuses which appeared in the process of taking the logarithm and differentiation on pluses, and sign of differential d on Δ, will get expression

$$\delta_\rho = \frac{\Delta\rho}{\rho} = \pm\left(\frac{\Delta m}{m} + 2\frac{\Delta r}{r} + \frac{\Delta h}{h}\right) 100\%\ . \tag{8}$$

From here we find

$$\Delta_\rho = \delta_\rho \cdot \rho\ , \tag{9}$$

In equalizations (9) and (10) $\rho,\ m, r, h$ are the mean values of quantities, and $\Delta m, \Delta r, \Delta h$ are absolute errors of the direct measuring of quantities, or errors of devices measuring. The record of final result is given in a kind:

$$\rho = (<\rho> \pm \Delta\rho). \tag{10}$$

A middle result and absolute error is rounded off after rules**:**

1) if a number which is cast aside is greater after 5, last number, that keep, increases on unity. For example, rounding off a number 21,277 to hundredth, it follows to write down 21,28;

2) if a number, that cast aside less after 5, last number which remains write with unchanging. Yes, rounding off a number 15,243 to hundredth, write down as 15,24;

3) if a number which is cast aside is a number 5, rounding off conduct so that the last number was even. For example, rounding off a number 19,65, it follows to write 19,6, and for a number 21,75 write down 21,8.

A values of physical quantities which are got at the laboratory measurings are approximate numbers. Mathematical actions with such numbers are subject set rules which are followings:

– at **addition and deduction** in final result remain so many decimal signs, how many a number has them with the least amount, for example 0,264 + 2,47 + 3,2531 = 5,9871 $\approx$ 5,99;

– like, at an multiplication and division in final result remain so many meaningful numbers, how many them is in a number with the least amount of meaningful numbers: 3,15* 0,2352 = 0,74. At getting up to the degree, or at getting of root in final result should remain so much meaningful numbers, how many them is in basis or under a root accordingly: 3,252 $\approx$ 10,56. In the case of taking the logarithm in mantis of approximate number should remain so many meaningful numbers, how many them is in a number which is taken the logarithm, for example ln 3,51 $\approx$ 1,25.

1.3 Graphic Image of Results of Measurings

Method of graphic presentation of information is useful then when it is necessity evidently to show motion of dependence $y(x)$, or when it is necessity graphically to determine a quantity y at those values x which directly in experiments was not measured .The example of construction of graph is drawn on the figure 1.3.

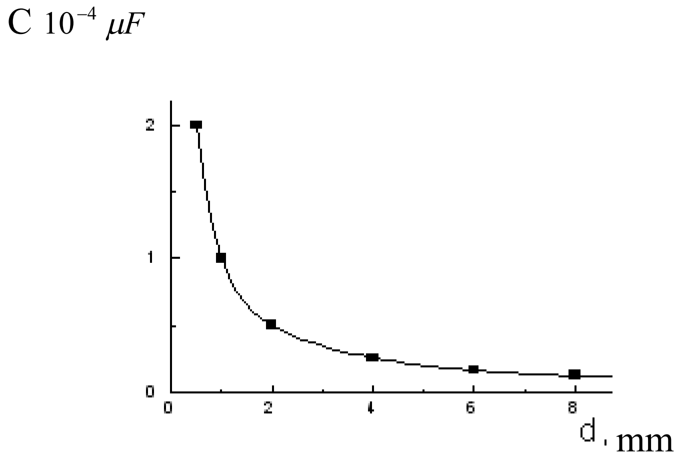

Figure 1.3 – Example of construction of a graph

Usually graph is built on a graph paper. For an independent variable, as a rule, choose abscise axis. On end of axis physical quantity is specified and its dimension. Then on the scale divisions are put, so, that distance between points have to be 1:2,5 units or these numbers, increased on $10^{\pm n}$. Order of scale, that $10^{\pm \mathbf{n}}$, take away scales on an end. An intersection axes not necessarily must answer a zero on one or both axes. Beginning of counting out on axes and scales intersection axes not necessarily must answer a zero on one or both axes. Beginning of counting out on axes and scales is chosen so that an experimental curve occupied all sheet.

After the choice of the system of co-ordinates on a square paper apply experimental points. Farther build a chart, they conduct a smooth curve as possible nearer to the points. Some points can find oneself pose by a curve. It is necessary to aspire to that for both sides from a chart there was approximately an identical amount of points. If some points considerably deviate from a curve, it can testify to the presence of misses. To find out reason of such rejections, it should repeat experiments for those values.

Sizes of sheet with a chart must be not less than half of page of laboratory register. As an example of correct construction of chart is represented on fig. 1.3 - the resulted chart of dependence of capacity of flat condenser from distance between plates.

1.4 Sequence of implementation of laboratory work and registration of report

Before to begin implementation of laboratory work, it is necessary carefully to familiarize with the methodical pointing to it. At the study of their maintenance it follows to pay regard to formulation of the physical phenomena and laws which are studied in this work. After studding of the proper pointing it is needed to put down the purpose and make the short compendium of laboratory work, in which the tables must be provided for bringing of information and calculation formulas. The results of the measurements, as well as the calculated values recorded in pre-prepared tables. The completed work must be shown to the teacher who checks it and puts a signature on the performance.

After treatment of the research data, a report should be made which should include: purpose of the work, devices and materials, calculation formulas for the measured values and their errors, as well as filled in tables, figures and the final result in the form:

$$X = <X> \pm \Delta X,$$

where $<X>$, ΔX are the mean value and the absolute error of the measured value. When registering a report, you should observe the following format: on the title page, on the top, indicate the names of the ministry, educational institution, department, in its center – the name of the laboratory work, its number. At the bottom of the sheet, indicate the student group and name surname of student, the date of completion of the work, as well as the position and surname of the teacher. On the last line write city, year.

The following sources are recommended for studying the basics of error theory.

1.5 List of sources

1. Zaydel A. N. Elemental estimates of measurement errors / A. N. Zaydel. – M. : Nauka, 1968. – 97 p.

2. Kucherenko I. M. Processing of the results of physical measurements / I. M. Kucherenko. – Kiev : High school, 1981. – 216 p.

3. General physics. Laboratory Workshop / Ed. I. T. Gorbachuk. – Kiev : Higher school. – 1992 – 512 p.

4. Physical Practice / Ed. prof. V. I. Ivveronova. – M. : Gosyzda phys.-math. Literature, 1962. – 956 p.

5. DSTU-2681-94. Metrology. Terms and definitions.

6. Taylor J. Theory of Mistakes / J. Taylor. – M. : Mir, 1985. – 272 p.

7. Kassandrova O. N. Processing of measurement results / O. N. Kassandrova, V. V. Lebedev. – M. : Nauka, 1970. – 104 p.

1.6 Sample report

MINISTRY of EDUCATION and SCIENCE of UKRAINE

Beketov National University of Urban Economy in Kharkiv

Department of Physics

Report

completed laboratory work № 5

"Determination of the acceleration of gravity by means of a mathematical pendulum"

Plan			Stood. (group.)	Name
Fact			Name	Signature

LABORATORY WORK № 1

THE STUDY OF THE LAW OF ROTATIONAL MOTION OF SOLID BODY WITH THE PENDULUM OF OBERBEK

1 Objective: to study the rotational motion of a pendulum; to determine the moment of inertia of cross-piece and moment of forces of friction.

2 Equipment.

2.1 The Pendulum of Oberbek.

2.2 Caliper.

2.3 Stopwatch.

2.4 The scale bar.

2.5. Loads.

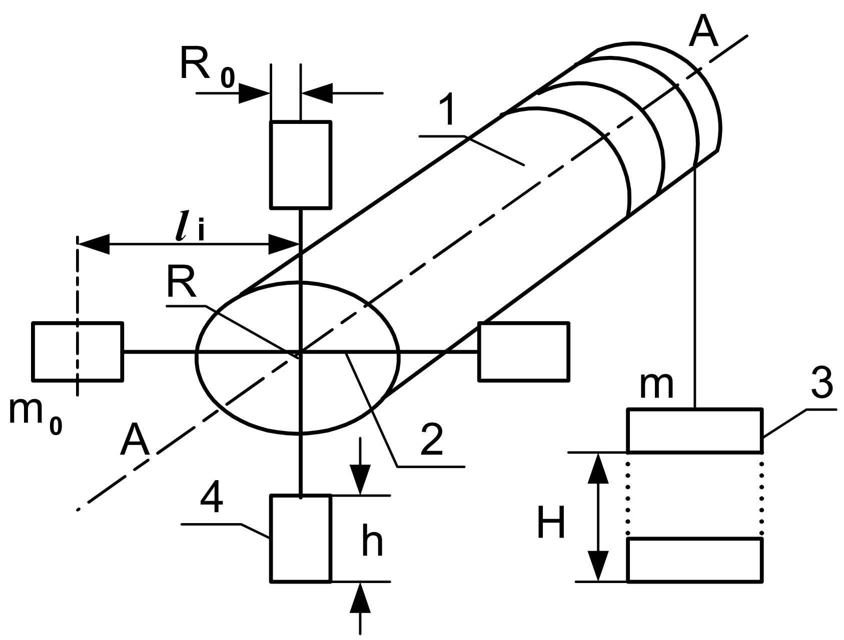

Figure 1.1 – Pendulum of Oberbek

3 Generals

One of the parameters characterizing the rotational motion of a solid body is the angular acceleration *β:*

$$\beta = \lim_{\Delta t \to 0} \frac{\Delta\omega}{\Delta t} = \frac{d\omega}{dt}. \tag{1.1}$$

It arises as a result of the effect on each element m_i of the mass the tangential force F:

$$F_i = m_i a_i = m_i \beta_i r_i. \tag{1.2}$$

The moment of this force *M* relative to the stationary axis *A-A* is:

$$\vec{M}_i = [\vec{r}_i \vec{F}_i] = m_i r_i^2 \vec{\beta}_i, \tag{1.3}$$

Full moment of the resultant force acting on the body:

$$\vec{M} = \sum_{i=1}^{n} M_i = \vec{\beta} \sum_{i=1}^{n} m_i r_i^2. \tag{1.4}$$

Scalar quantity

$$J_i = \sum_{i=1}^{n} \Delta m_i r_i^2, \tag{1.5}$$

is the moment of inertia of a system of point particle where $J_i = \Delta m_i r_i^2$ is the moment of inertia of *i*-th point particle; Δm_i = mass of particle; r_i = the distance from axes of rotation to particle. The formula (1.5) holds for a solid with the sign $\cong$ in relation (1.5) (in this case *i* is the number of pitching *n* to small pieces of body). From a formula (1.5) evidently, that the moment of inertia of solid equals the sum of products of elementary masses on the square of their distances to the examined axis. Expression (1.5) is the more precisely, than less is Δm_i and that a sum (1.5) is erected to the integral,

$$I = \int_v r^2 dv = \int_v r^2 \rho \, dv. \tag{1.6}$$

where r = s distance from an element of volume dv to the axis of rotation;

ρ = density of body;

v = the volume of a body.

Moment of inertia is a scalar quantity. It plays as role at rotator motion, as the mass at translational motion, that is the measure of inert of solid at his rotation. Moment of inertia is the additive quantity and it means that the moment of inertia of the solid equals the sum of moments of inertia of his separate parts.

Basic equation of dynamics of rotation motion is

$$\vec{M} = \dot{J}\,\vec{\beta}, \tag{1.7}$$

where moment $\vec{M}$ = resultant moment of forces;

$\vec{\beta},$ = angular acceleration.

Projection of equation (1.7) onto the axis of rotation yields

$$M = j\beta$$

4 The order of performance

4.1 Measure the radius R of the pulley at the point where the thread is wounded, and the height of fall H of the load m (height H for all experiments leaves unchanged).

4.2 Fasten 4 loads mass m_0 on the same axis of AA at the distance l_i (l_i teacher sets).

4.3 Identify the radius R_0 and height h_0 of additional loads 4.

4.4 By the end of thread hang alternately known masse m and using stopwatch, determine the time t of fall from a height H.

4.5 Using experimental data, define the following physics characteristics:

a) acceleration of loads a by formula $a = \dfrac{2H}{t^2}$;

b) angular acceleration β_i) by formula $\beta = \dfrac{a}{R}$;

c) torques of force of stretching thread M_t by formula

$$M_t = m(g-a)R.$$

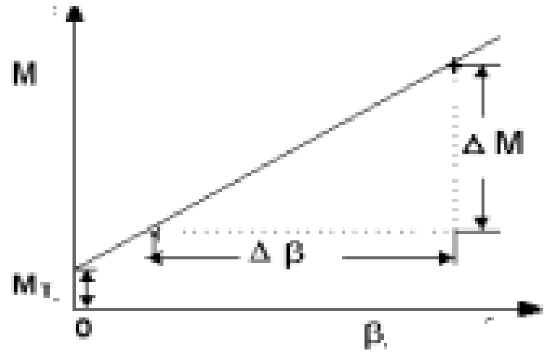

Figure 1.2 – Plot dependence $M_н = f(\beta)$

Table 1.1

№	m_i	t	T_m	a	β	M	l_i	R	R_0	H	h_0	J_m	J	J_{xp}	M
Ex	kg	s	s	m/s^2	rad/s^2	Nm	m	m	m	m	m	kg·m^2	kg·m^2	kg·m^2	Nm
1															
2															
3															
4															
5															
6															

4.6 All measured and calculated results must carry to table 1.1

4.7 With the obtained values of β and M, plot dependence $M_н = f(\beta)$ as shown in figure 1.1.

4.8 With graphics (Fig.1.2) determine the moment of inertia of the pendulum: $J = \dfrac{\Delta M}{\Delta \beta}$ and the value M_1.

4.9 Using the formula (1.8), determine the moment of inertia $J_ь$ of loads 4

$$J_m = 4\left(\frac{m_0}{12}\left(3R_0^2 + 3r_0^2 + h_0^2\right) + m_0 l_i^2\right), \tag{1.8}$$

where $m_0 = 0{,}25$кг;

$r_0 = 5\cdot10^{-3}$м.

4.10 Using and founded above values J_m i J, calculate the moment of inertia of cross J_c.

5 Control questions and tasks

1. Name quantities measuring in experiments, and those that are determined after by calculation formulas.

2. Write basic equation of dynamics of rotatory motion of solid.

3. Write the law of motion of load m.

4. What is named the moment of inertia of solid in relation to the axis of rotation?

5. Does property of additivity consist in what?

6. Give determination to the moment of force in relation to a point (axes).

7. How does determine direction of vector of moment of force?

8. Formulate the theorem of Steiner.

LABORATORY WORK № 2

Weighing on an analytical balance and determination of density of bodies

1 Object of work: to study the structure of lever analytical scales; mastering the technique of precision weighing and determining the density bodies of regular geometric shape.

2 Equipment and materials

2.1 Lever analytical balance.

2.2 The bodies of regular geometric shape.

2.3 Caliper.

3. General provisions

In this laboratory work lever analytical equivalence scales are used. Its are represented schematically on the figure 2.1.

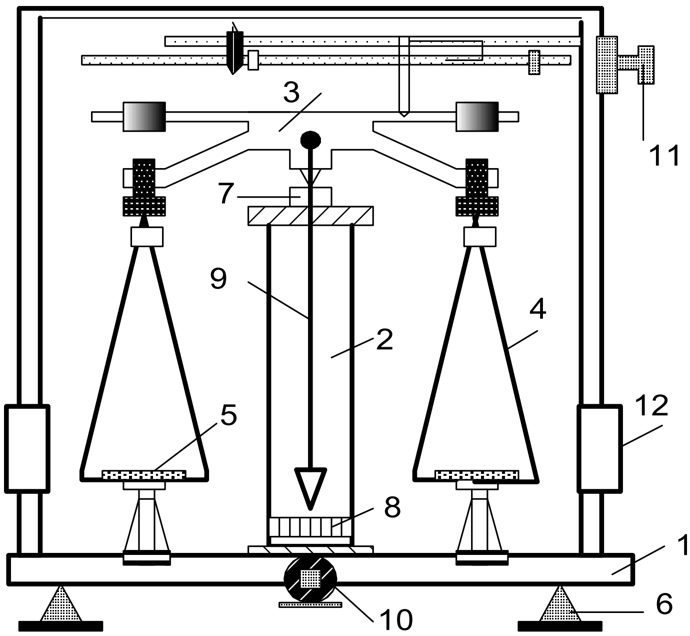

Figure 2.1 – Schematically representation of lever analytical equivalence scales

Scales, consist of support 1, column 2, rocker arm 3, two earrings 4 and two bowls of scales 5. The stand 1 is based on legs 6 having screws for adjusting the device. On the stand is a column of scales, on top of which is a flat pillow of solid material. The crochet-layer fluctuates on the pillow around the edge of its base prism 7. At equal distances from the support edge there are prisms on which the skeletons of scales are hung. The equilibrium position is indicated on the scale 8 of the veto graph On the eyepiece of the ideograph, in relation to which the arrow 9 moves with an optical scale, there is a sight line. To stop the fluctuations of the weights and release the prism from the load as arête 10 serves. When the small limb of the mechanism 11 is rotated, it hangs or removes tens of milligrams, and when it rotates its large limb – hundreds of milligrams. The accuracy of the leverage analytical weights used is 0.1 mg.

4 Determination of density of bodies of regular geometric shape

Density of matter is called physical quantity that is numerically equal to the mass of matter in unit volume. If the body is inhomogeneous mass m, and its volume V, then high density, defines as follows:

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

Apparently, to determine the average density necessary to determine volume and body weight. Volume of some bodies of regular geometric shape is determined by the formulas:

1) volume truncated cone – $V = (1/3)\,\pi\,(R^2 + r^2 + Rr)\,H$, (2.2)

2) volume circular cone – $V = (1/3)\,\pi\,R^2 H$, (2.3)

3) continuous cylinder – $V = \pi\,R^2 H$, (2.4)

4) hollow cylinder – $V = \pi\,(R^2 - r^2)H$, (2.5)

5) sphere – $V = (4/3)\,\pi\,R^3$, (2.6)

where H = height, R and r =radius of bodie.

5 Order of work

5.1 Weigh the body. To do this, put the body into left plate scales, and on the right – weight.

5.2 Set balance, write weight (weight weights plus count on the limb of a figure 2.1 loading device, plus a countdown on a scale veytohraf).

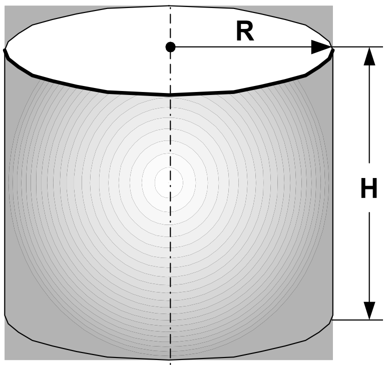

Figure 2.2 – Determination the geometric dimensions of the continuous cylinder

5.3 Determine the geometric dimensions of the body, using appropriate – formula (2.2) – (2.6), calculate its volume V.

5.4 According to the formula (2.5) calculate the material density ρ.

5.5 Make calculations relative $\Delta\rho/\rho$ and absolute $\Delta\rho$ errors.

In particular, for continuous cylinder shown in (fig. 2.1) are according to the formula (2.4)

$$\frac{\Delta \rho}{\rho} = \left(\frac{\Delta m}{m} + \frac{2\Delta R}{R} + \frac{\Delta H}{H}\right) 100\%, \tag{2.7}$$

$$\Delta \rho = \rho \left(\frac{\Delta m}{m} + \frac{2\Delta R}{R} + \frac{\Delta H}{H}\right), \tag{2.8}$$

The results swing to the table. 2.1.

Table 2.1

Material	m	Δm	R	H	V	ρ	$\Delta\rho$	$\Delta\rho/\rho$	ΔR, ΔH
	kg	kg	m	m	m^3	kg/m^3	kg/m^3	%	m

6 Control questions

1. What is called the weight of the body?

2. How is body weight determined?

3. How is the average density of matter determined?

4. Whether to change the weight of the body if it moves with acceleration, vertical down (up), or if is it at rest?

5. Causes of weightlessness of the bodies.

LABORATORY WORK № 3

THE DETERMINATION OF THE MOMENT OF INERTIA OF THE BODY WITH A PERIOD TORSIONAL OSCILLATIONS

1 Objective: determining of inertia moment of the rod about an axis passing through its centre of mass.

2 Equipment and materials

Stopwatch.

3 Generals

Turning oscillations can be easily looked after by the experimental setting, schematically presented on Fig.3.1. It includes a steel wire fastened from above on a stand. On the lower end of wire the massive bar of AB is hardly fastened, which the moment of inertia is determined. If we turn the rod a certain angle applied an external moment of forces $\vec{M}$ it will deformate steel wire. A reaction of wire is the appearance of restoring moment of elastic force $\vec{M}_e ,\dots \vec{M}_e = -\vec{M}$.

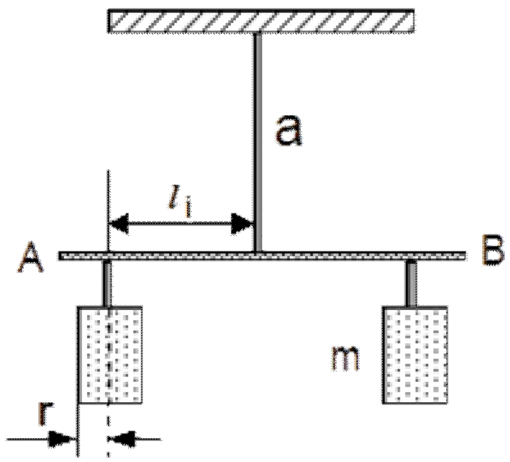

Figure 3.1 – Schema of experimental setting

Equation of motion of a torsion pendulum is differential equation of second order

$$\frac{d^2\varphi}{dt^2} + \omega_0{}^2\varphi = 0, \tag{3.1}$$

where φ = angular displacement;

ω_0=natural circular frequency (natural, because it is proper, present at the given oscillating system one)

$$\omega_0{}^2 = \frac{k}{J}, \tag{3.2}$$

and k=constant of elasticity of the thread on which rod with the loads are suspended, J=moment of inertia of pendulum. Equation (3.1), is equation of motion of a pendulum. The solution of this equation is

$$\varphi = \varphi_0 \cos(\omega_0 t + \alpha), \tag{3.3}$$

where φ_0 = maximal deviation angle of mobile part of the pendulum from position of equilibrium, α = an initial phase of vibrations.

It is possible to see that a bar carries out harmonious vibrations with a period:

$$T = \frac{2\pi}{\omega_0} = 2\pi\sqrt{\frac{J}{k}}, \tag{3.4}$$

Tacking to the suspended rod the second body with the moment of inertia of J_1, it can change the moment of inertia of the system, and also period of its vibrations

$$T_1 = 2\pi\sqrt{\frac{J + J_1}{k}}, \tag{3.5}$$

From formulas (3.4) and (3.5) determining and excluding then constant k it is possible to find the moment of inertia of the rod

$$J = J_1\frac{T^2}{T_1^2 - T^2}, \tag{3.6}$$

4 The work order

4.1 Spin the pendulum by angle about 30° and then leave. Missed a few floations, necessary to soothe the system, determine with a stopwatch the time t, during which n full oscillations occurred (take n = 20).

4.2 The period of oscillation of the free (unloaded) rod can be find by the formula:

$$T = \frac{t}{n}, \tag{3.7}$$

4.3 Hang on the rod at the equal distances from the axis of rotation the bodies (e.g., cylinders) of equal mass and determine $T_{1.}$ The moment of inertia of the cylinder about the rotation axis passing through the center of inertia of the cylinder, is the expression:

$$J_0 = \frac{m\,r^2}{2}, \tag{3.8}$$

Since the rotation occurs about an axis which is at a distance l from the cylinder axis, the total moment of inertia of one cylinder according to the Steiner's theorem

$$J_1 = \frac{mr^2}{2} + ml_1^2, \tag{3.9}$$

Thus, additional moment of inertia J_1 for two cylinders, that is suspended on the ends of rod (on identical distances from the axis of rotation), is found after by a formula:

$$J_1 = 2\left(\frac{mr^2}{2} + ml_1^2\right), \tag{3.10}$$

where m = mass of cylinder; l_i = the distance from the axis of rotation to the axis of cylinder; r – radius of cylinder.

In the future measurements of the oscillation periods T_1, T_2, T_3 are provided at different distances of the weights from the axis of rotation l_i, l_2, l_3. Then, according to the experimental results, calculate the inertia moment of additional bodie J_i and total one J.

All the results are entered in the table 3.1.

Table 3.1

№	l	n	t_i	t_m	T_m	J_i	J	Δt	ΔT	ΔJ	$\Delta J/J$
Exp	m		s	s	s	kg·m^2	kg·m^2	s	s	kg·m^2	%
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											

The inertia moment of the rod is determined by formula (3.6) where T period of oscillation of the free (unloaded) rod.

5 Control questions and tasks

1. Give the definition the inertia moment of a point particle, of a body.

2. What is the physical essence of moment of inertia?

3. Write and explain the basic law of dynamics of rotational motion.

4. Formulate the theorem of Steiner.

LABORATORY WORK № 4

DETERMINATION OF RENEWAL COEFFICIENT AND TIME OF ELASTIC BALLS HITTING

1 Object of work: To define the coefficient of renewal and time of hitting in the case of elastic central blow of balls.

2 Equipment and materials:

Setting consist of two balls, suspended on metallic filaments conducting electric current (see fig. 4.1), and electric scheme, composed of the source of direct-current *E,* electromagnets M_1 and M_2; resistance *R*; condenser *C;* measuring device of voltage *V* (see fig. 4.2).

3 Generals

At the central absolutely elastic blow of two balls (on the basis of laws of conservation of energy and momentum) relative speed remains unchanging in magnitude. In the case of not quite absolutely elastic blow part of kinetic energy of balls passes into energy of remaining deformation which results in diminishing of them relative speeds. For a quantitative estimation, diminishing of relative speed is entered a coefficient of renewal *K,* that characterizes elastic properties of material which the given ball are made of

$$K = \frac{\left|\vec{u}_1 - \vec{u}_2\right|}{\left|\vec{v}_1 - \vec{v}_2\right|} \tag{4.1}$$

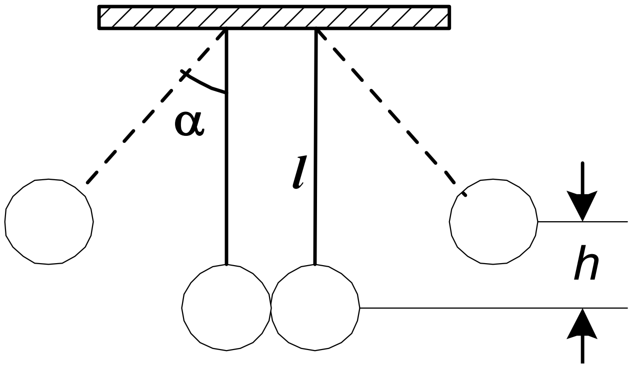

Figure 4.1 – Scheme of experimental setting

where $\vec{v}_1, \vec{v}_2$ and $\vec{u}_1, \vec{u}_2$ = speeds of balls before and after hitting accordingly.

Let two identical balls (fig. 4.1) hang on the filaments of identical length *l.* If to decline both balls on identical angles and release, speeds them in the moment of hitting will be identical.

Speed of ball can be expected, using relation, that swims out from the law of conservation of energy:

$$\frac{mv^2}{2} = mgh \tag{4.2}$$

where h = height of getting up of ball.

Let us find relation between the height h of and corner α . From figure 4.1 swims out, that

$$h = l(1 - \cos\alpha_0) = 2l\sin^2\frac{\alpha_0}{2}, \tag{4.3}$$

At small angles it may put for coefficient of renewal

$$\sin^2\frac{\alpha_0}{2} \approx \left(\frac{\alpha_0}{2}\right)^2$$

Then from correlations (4.2) and (4.3)

$$v = \alpha_0 \sqrt{gl}. \tag{4.4}$$

From an analogical formula it is possible to find speed of ball after a blow and to define the quantity *K*. Really, if in a formula (4.1) to put $\vec{v}_1 = -\vec{v}_2 = \vec{v}$ *and* $\vec{u}_1 = -\vec{u}_2 = \vec{u}$, then it is possible to write down

$$K = \frac{|\vec{u}|}{|\vec{v}|}, \tag{4.5}$$

Taking into account correlation (4.4), the formula (4.5) acquires a kind

$$K = \frac{\alpha_1}{\alpha_0}\,., \tag{4.6}$$

where α_0, α_1 = rejections of balls before and after hitting. Because the reducing of corner of rejection after the first blow is small, that causes errors in determination of *K* from a formula (4.6), so it is necessary to measure α after about 10 hitting. In this case a formula (4.6) must be modified. For the first hitting $K = \frac{\alpha_1}{\alpha_0}.$, for the second hitting $K = \frac{\alpha_2}{\alpha_1}$. and others like that; for the n-th hitting $K = \frac{\alpha_n}{\alpha_{n-1}}$. If to multiply these equalizations, we will obtain

$$K = \sqrt[n]{\frac{\alpha_n}{\alpha_0}}, \tag{4.7}$$

Time of hitting of two balls is determined experimentally as the time of the discharge of condenser in obedience to a scheme which is represented on figure 4.2.

It must for it to plug balls in electric circuit which has resistance *R* and the capacity *C*, and charge the condenser to voltage u_0. Then make discharge condenser *C* and measure by a voltmeter *V* voltage throw condenser after certain number hitting of balls (see fig. 4.2).

Voltage on the condenser in course of time to hitting of balls is determined by formula

$$u_n = u_0 \, exp\left(- \frac{n\tau}{RC} \right).,\tag{4.8}$$

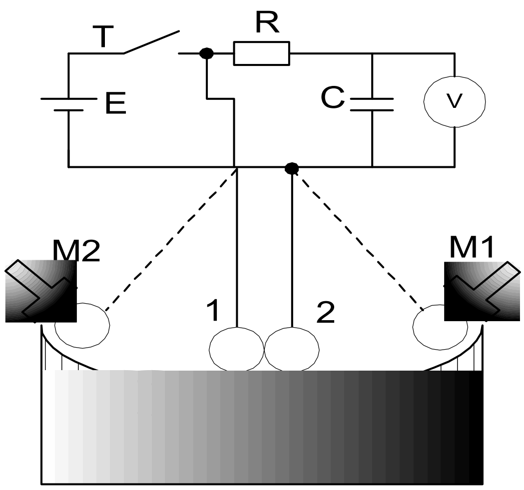

Figure 4.2 – Scheme fo definition the. time of hitting of balls

Taking logarithm of (4.8) we get

$$\tau = \frac{RC}{n} ln \frac{u_0}{u_n} ,\tag{4.9}$$

where u_0 = initial voltage, u_n = voltage after the *n-th* hitting of balls. As known, at the not resilient blow of two balls their kinetic energy passes to potential energy of elastic deformation and energy of remaining deformation W. It is possible to define it by writing down the law of conservation of energy for the blow of two balls:

$$\frac{m v_1^2}{2} + \frac{m v_2^2}{2} = \frac{m u_1^2}{2} + \frac{m u_2^2}{2} + 2W ,\tag{4.10}$$

Then from equation (4.10) we arrive at expression:

$$m v^2 = m u^2 + 2W ,\tag{4.11}$$

and at last to relation:

$$W = \frac{m v^2}{2}\left(1 - K^2\right), \tag{4.12}$$

The quantity of the overage power of a blow F is founded from relation

$$\int_0^{\tau} F dt = \int_{-v}^{u} m dv , \tag{4.13}$$

(The signs of speeds take according to their direction in relation to the vectors of force).

It is possible to write down as a result of integration

$$F = \frac{m v}{\tau}\left(1 + K\right), \tag{4.14}$$

3 Description of device

In setting (fig. 4.2) is used two metallic balles 1, 2, suspended on bifilar suspensions of length l, that provide oscillations of bales in a vertical plane. Bales are contained in the declined position by two electromagnets M_1 and M_2. Last owns it is possible easily to move on a scale. Corners of rejection of bales are counted from position of equilibrium. Electromagnets and integrating RC-circuit are supplied from the source of direct-current. Voltage drop on a condenser in his charged state and during a discharge at the blow of bales is measured by a digital voltmeter.

4 Sequence of implementation of work

4.1 To define the coefficient of renewal K:

a) to switch on electromagnets and set them so that balls were declined on identical initial angle α_0 (12÷20°);

b) to switch off electromagnets and begin counting out of hitting (initial angle α_0 and the number of hitting n is set by a teacher);

c) to write down the angle of rejection of balls α_n after the last hitting;

d) to repeat experiments at other initial angles and calculate the mean value of *K* by formula (4.7). (For measuring to take not less than 4 initial corners).

4.2 To define the. time of hitting of balls τ:

a) setting balls on a angle α_0 to activate the switch *T* (fig. 4.2) and charge a condenser to voltage u_0;

b) to break switch *T*, to set balls in motion and then after to write down the indication of voltmeter after the *n-th* hitting;

Table 4.1

α_0 (grad)	n	Left scale, (grad)			Right scale, (grad)			$\bar{\alpha}_n$ (grad)	K	v m/s	n	u_0	u_1	u_2	u_3	$\bar{u}$	τ	W
		α_1	α_2	α_3	α_4	α_5	α_6					V	V	V	V	V	s	J

c) repeat experiments at other initial angles and to define a mean value τ by formula (4.9);

d) express α_0 in radians. Calculate the magnitude of speed by formula $v = \alpha_0\sqrt{gl}$. Pay attention that capacity of condenser *C*, value of resistance *R,* and also mass of balls and length of pendant of the balls l are indicated on setting.

4.3 Calculate energy of remaining deformation W by formula (4.12), using experience data for α_0, V and K.

a) build the dependence $W = f(v)$.

Bring the got results to table 4.1.

4.4 Calculate the relative and absolute errors of quantity K after the proper formulas

$$\frac{\Delta K}{K} = \left[\frac{\Delta\alpha_n}{n\alpha_n} + \frac{\Delta\alpha_0}{n\alpha_0}\right] 100\%, \qquad (4.15)$$

$$\Delta K = K\left[\frac{\Delta\alpha_n}{n\alpha_n} + \frac{\Delta\alpha_0}{n\alpha_0}\right]. \qquad (4.16)$$

5 Control questions

1. What properties of material are characterized by a constant K, and what limits its magnitude can change in?

2. Why for determination of K does we take the series of blows?

3. What factors influence on a value τ?

4. How does kinetic energy of balls change at the different types of blow: absolutely resilient, not resilient, absolutely not resilient?

5. Can a value of K be greater than 1?

6. Describe the method of determinaion of hitting time.

LABORATORY WORK № 5

DETERMINATION OF GRAVITATIONALFORCE ACCELERATION WITH HELP OF MATHEMATICAL PENDULUM

1 Object of work: to define the acceleration of the free falling by means of mathematical pendulum.

1.1 Devices and equipments.

1.2 Setting for the study of harmonic oscillations.

1.3 Stop-watch.

1.4 A movable indicator for fixing of length of pendulum**.**

2 Generals

Oscillatory motion is the process distinguished by a certain degree of repetition. Harmonic oscillations take place by law of sine or cosine. It is comfortably to observe such oscillations by means of mathematical pendulum.

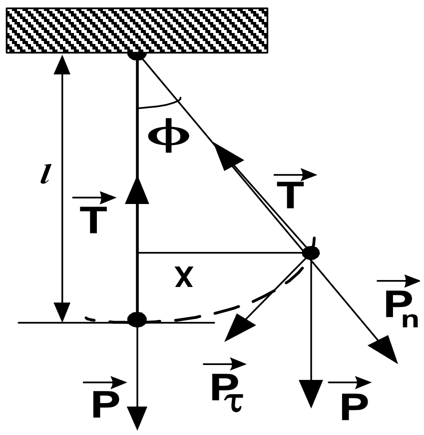

Figure 5.1 – Mathematical pendulum

Mathematical pendulum is defined as an idealized system consisting of a point particle suspended on weightless and unstretchable string (fig. 5.1).

At deviation of pendulum from position of equilibrium on the angle φ tangent component of gravitational force $P_\tau = P \sin\varphi$, is directed to position of equilibrium.

In approaching of small angle ($\sin\varphi \approx \varphi$), $P_\tau = P\varphi$ and expression for deviation from position of equilibrium can be represented in the form

$$x = l\varphi, \tag{5.1}$$

where l = length of pendulum (distance from the point of suspending to the centre of gravity of loud).

Motion of pendulum takes place under the action of restoring force

$$P_\tau = P\varphi = mg\frac{x}{l}$$

which magnitude changes proportionally its deviation from a normal, and directed to the position of equilibrium. In accordance with Newton's second law equation of motion acquires the form:

$$m\ddot{x} = -mg\frac{x}{l}$$

or

$$\ddot{x} + \omega^2 x = 0, \tag{5.2}$$

where $\omega^2 = \frac{g}{l}$, (ω = circular frequency of mathematical pendulum). The solution of equation (5.2) has the form

$$x = A\cos(\omega t + \alpha), \tag{5.3}$$

where A= amplitude , $(\omega t + \alpha)$ = fase, α= initial phase of harmonic oscillations. As a period of cosine is 2π, period of oscillation T it is possible to find from equation:

$$A\cos[\omega(t + T) + \alpha] = A\cos(\omega t + 2\pi + \alpha), \tag{5.4}$$

So

$$T = 2\pi\sqrt{\frac{l}{g}}, \tag{5.5}$$

where g = gravitational constant. At the large angles of rejection the equation (5.2) becomes useless, as it describes motion of point particle on the arc of small curvature (near to the straight line). In this case motion of pendulum under the action of rotary moment also will be periodic, but not harmonic, as T is dependent upon amplitude. Deciding equalization (2.6). Solving accurate equation

$$ml^2\ddot{\varphi} = -mgl\sin\varphi\,, \tag{5.6}$$

it can to get expression for the period of vibrations:

$$T = 2\pi\sqrt{\frac{l}{g}}\left[1+\left(\frac{1}{2}\right)^2\sin^2\frac{\alpha}{2}+\left(\frac{1\cdot 3}{2\cdot 4}\right)^2\sin^4\frac{\alpha}{2}+\cdots\right], \tag{5.7}$$

The analysis of the obtained results shows that formula (5.5), at exactness of measuring of period of vibrations (to 0,2) may be used for rejection corners of pendulum $\alpha \leq 10$ grad. Let us obtain calculation formulas. Let us write equation (5.5) in form

$$T^2 = \frac{4\pi^2}{g}l\,, \tag{5.8}$$

If to obtain experimentally dependence of $T^2 = f(l)$, after the angle of slope

$$tg\alpha = \frac{4\pi^2}{g} = \frac{T_2^2 - T_1^2}{l_2 - l_1}$$

it is possible to define the absolute value of parameter g by formula

$$g = \frac{4\pi^2(l_2 - l_1)}{T_2^2 - T_1^2}\,, \tag{5.9}$$

In this case the increase of quantities $(l_2 - l_1)$ and $(T_2^2 - T_1^2)$ is taken by from the line $T^2(l)$,that summarizes plenty of experimental points. From it exactness is at the calculations of acceleration of the free falling substantially increases.

3 Description of experimental plant

For implementation of laboratory work the specially constructed device (fig. 5.2) is used. It consists of bracket 1, on which fasten a lifting mechanism 2 with fixing 3, and also line 5, along which a movable indicator 7 (necessary for counting out of length of pendulum) moves.

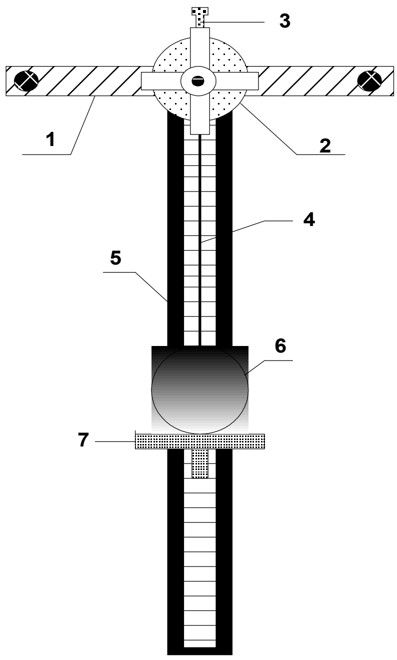

Figure 5.2 – Experimental plant

To mobile part of lifting block which provides the smooth adjusting of length of pendulum 4, a ball 6 suspended on the long filament.

4 Sequence of implementation of work

4.1 Set a ball in overhead part of measuring scale and by a movable indicator 7 to define position of it under edge of a body l_1 (fig. 5.2).

4.2 Displace a ball on 2÷3 from position of equilibrium and to release. Define by a stop-watch time of t_1 for n =30 full - periods. Repeat experiment else twice. Calculate the period of ondulations of the pendulum by formula

$$T_1 = \frac{t_{av}}{n}, \qquad (5.10)$$

By means of lifting block 2 increase length of pendulum on 20÷25cm. To write down l_2. Repeat P. 4.1–4.2 and calculate the period of vibrations T_2:

$$T_2 = \frac{t_{av}}{n}, \tag{5.11}$$

4.3 Continue analogical experiments yet at three values l of pendulum. To define accordingly the quantities l i T_i and add them to theTable 5.1.

4.4 According to the known values of l_i and T_i^2, plot the dependence $T^2 = f(l)$ as shown in figure 5.3.

4.5 From the plotted graph, we must take the value of Δ (l) and $\Delta(T^2)$ for two arbitrary points and using the expression (5.9) to find the value of g.

4.6 Calculate the absolute Δg and relative Δg/g errors according to formulas (5.12) and (5.13) and record the final result. All experimental data are included to table 5.1.

$$\frac{\Delta g}{g} = \left(\frac{\Delta \ell_1 + \Delta \ell_2}{\ell_1 - \ell_2} + \frac{2T_1\Delta T_1 + 2T_2\Delta T_2}{T_1^2 - T_2^2} \right) \cdot 100\%, \tag{5.12}$$

$$\Delta g = g\left(\frac{\Delta l_1 + \Delta l_2}{l_1 - l_2} + \frac{2T_1\Delta T_1 + 2T_2\Delta T_2}{T_1^2 - T_2^2} \right), \tag{5.13}$$

where the magnitudes Δl and ΔT represent the instrumental errors of the measuring devices used in the experiments. Note that as the quantity ΔT, we must take the value. This is due to the fact that a person can not separately take time intervals less than 0,1s. Therefore, when measuring the time with a manual activation stopwatch, the experimenter will double errors of 0,1s (at moments of its activation and shutting off). Therefore, regardless of the precision of the stopwatch, the maximum error will be 0.2 s. All experimental data are included to table 5.1.

Table 5.1

№	l_i	t_i	t_{av}	T_{av}	T_{av}^2	Δl	Δt	ΔT	g_{av}	Δg	$\Delta g/g$
	m	s	s	s	s^2	m	s	s	m/s^2	m/s^2	%
1											
2											
3											
4											
5											
6											
7											
8											
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The end result should be written as:

$$g = g_{cp} \pm \Delta g \qquad (5.14)$$

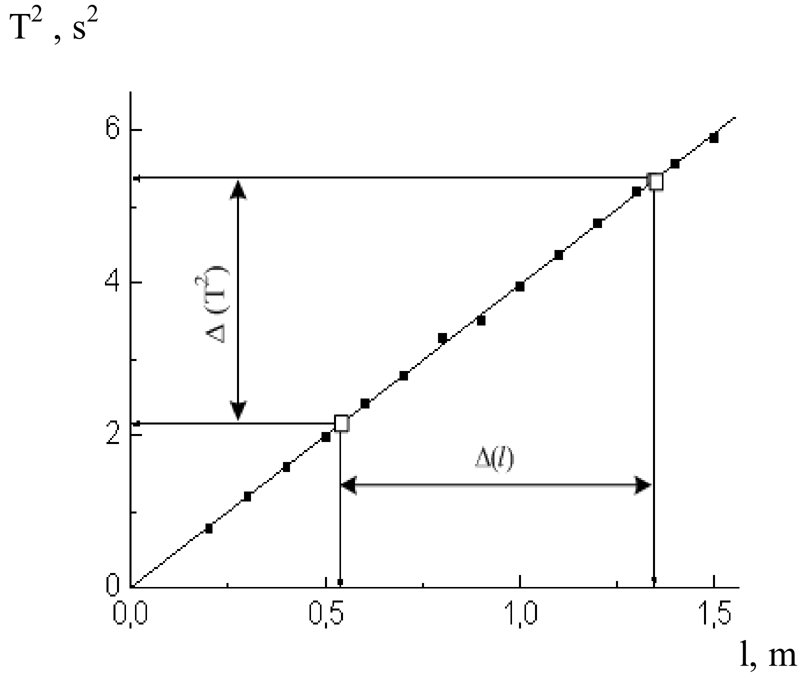

Figure 5.3 – Plot the dependence T^2 = f(l)

5 Control questions

1. What is called mathematical pendulum?

2. What period of oscillations of the mathematical pendulum depends on?

3. What is the period of oscillation of the pendulum?

4. Which oscillations are called harmonious and how do its appear?

5. What does the magnitude of the acceleration of gravity depend on?

6. Why the angle of the pendulum deviation from the equilibrium position must be small?

Виробничо-практичне видання

Методичні рекомендації

до виконання лабораторних робіт

з курсу

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ЧАСТИНА 1 «МЕХАНІКА»

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

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