Ministry of Education and Science of Ukraine
NATIONAL TU DNIPRO POLYTECHNIC

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PHYSICAL FUNDAMENTALS OF MECHANICS

Training manual

Recommended by the Scientific Council of the National Technical University "Dnipro Polytechnic" for foreign students of technical directions of training

NTU DNIPRO POLYTECHNIC

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Recommended by the Scientific Council of the National Technical University "Dnipro Polytechnic" (Protocol #8 of 13 June, 2018) for foreign students of technical directions of training

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Given manual is worked out in consequence with the program of the normative courses “Physics” and “General Physics” for foreign students of technical directions of training, when they study the chapter of the course “Physical Fundamentals of Mechanics”. It may be explored by other students which study noted courses in English. The manual contains the work program of course with recommended literature, methodical recommendation for problems solving, brief theoretical knowledges upon the physical fundamentals of mechanics and problems texts for independence solving.

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1. PROGRAM OF THE COURSE "PHYSICS"

(chapter “Physical Fundamentals of Mechanics”)

Introduction

1. Subject of physics. Physical methods of research, experiment, hypothesis, theory. The concept of physical models. Physics role in the development of technology and the impact of technology on the development of physics. Computers and mathematical modeling in modern physics.

2. The relationship of physics to philosophy and other sciences. The common structure and objectives of physics studying.

<u>Physical fundamentals of mechanics</u>

Introduction to Mechanics

3. Subject of mechanics. Classical, relativistic and quantum mechanics. The concept of the mechanical movement. Frame of reference. Classical conceptions of space and time.

Elements of kinematics

4. Kinematics of a material point. Displacement, distance. Velocity and acceleration as the radius- vector derivatives with respect to time. Normal and tangential acceleration.

5. Kinematics of rigid body. Translational and rotational motions. Angular velocity and angular acceleration, their relationship to linear ones.

The dynamics of a material point and the translational motion of rigid body. Forces in mechanics

6. Newton's first law and inertial frame of reference.

7. Mass, momentum. The major task of classical mechanics. Force.

8. Newton's second law as an equation of motion. Force as the derivative of the point momentum with respect to time. Newton's third law.

9. The system of material points. Center of inertia. Theorem about the center of inertia motion.

10. *Forces in mechanics. Elasticity forces, Hooke's law. Friction forces.*

11. *The forces of gravitation, law of universal gravitation. Body weight. The concept of weightlessness.* .

The dynamics of a rigid body which has a fixed axis of rotation

12. Point and rigid body moment of inertia relative to the axis.

13. Force moment and angular momentum of the particle relatively the axis. Angular momentum of a rigid body relatively the axis. Moments equation.

14. Motion equation of a rigid body which has a fixed rotation axis. Force moment as the derivative of the body angular momentum with respect to time.

Conservation laws

15. Conservation laws and the solution of the fundamental problem of mechanics. Conservation laws and space and time symmetry properties.

16. The law of conservation of momentum, its relationship to Newton's third

law. The law of conservation of momentum as a fundamental nature law. *Reactive motion*.

17. Work of an alternative force. Power. The work of elasticity, gravity and friction forces. The concept of conservative forces and conservative system.

18. Energy as a general motion and interaction measure. Mechanical energy. The kinetic energy of the particle and systems of the particles. The kinetic energy of a rigid body with a fixed rotation axis and of the plane motion.

19. The potential energy of a conservative system. Total mechanical energy. Law of energy conservation in mechanics as a special case of a general law of energy conservation and transformation.

20. *Applying of the laws of energy and momentum conservation to elastic and inelastic collisions.*

21. The law of angular momentum conservation. The concept of the gyroscopic effect, its usage in the automatic systems.

Elements of the special relativity theory

22. The relativity principle in classical mechanics. Galilean transformations. Velocities addition law in Newtonian-Galilean mechanics. The conception of the Galilean invariants.

23. Concept of simultaneity analysis. Einstein's postulates. Lorentz transformations.

24. Relativistic addition law of velocities. Relativity of length and time. The interval between events, its invariance.

25. Mass and momentum of the relativistic particle. Relativistic motion equations. Newtonian – Galilean mechanics as a limiting case of a relativistic mechanics.

26. Kinetic energy, self-energy and total energy of the relativistic particle. The conception of the coupling energy of the relativistic system.

Tests on the theoretical material
Laboratory workshop on physical principles of mechanics.
Control tasks to laboratory work on physical principles of mechanics /7/

#	*Individual task №1*	#	*Individual task №1*	#	*Individual task №1*	#	*Individual task №1*
1.	Option 1	**9.**	Option 9	**17.**	Option 7	**25.**	Option 5
2.	Option 2	**10.**	Option 10	**18.**	Option 8	**26.**	Option 6
3.	Option 3	**11.**	Option 1	**19.**	Option 9	**27.**	Option 7
4.	Option 4	**12.**	Option 2	**20.**	Option 10	**28.**	Option 8
5.	Option 5	**13.**	Option 3	**21.**	Option 1	**29.**	Option 9
6.	Option 6	**14.**	Option 4	**22.**	Option 2	**30.**	Option 10
7.	Option 7	**15.**	Option 5	**23.**	Option 3	**31.**	Option 1
8.	Option 8	**16.**	Option 6	**24.**	Option 4	**32.**	Option 2

LITERATURE

Principal

1. Berkeley Physics Course. Mechanics. Volume I. Second Edition.*)

2. I.V.Savelyev. Physics. A General Course. Mechanics and Molecular Physics. Volume I.*)

3. M.Sh. Pevzner. Lectures.
   http://physics.nmu.org.ua/ua/personal/Pevzner/01.pdf
   http://physics.nmu.org.ua/ua/personal/Pevzner/02.pdf
   http://physics.nmu.org.ua/ua/personal/Pevzner/03.pdf
   http://physics.nmu.org.ua/ua/personal/Pevzner/04.pdf

4. M.Sh. Pevzner. Lectures Conspect.

*) The marked materials are located on the electronic disk http://edisk.ukr.net with account: name – physics.nmu@ukr.net, password: KafFiZikI34.

Notation. Items typed by italic are supposed to be studied yourselves.

2. METHODICAL RECOMMENDATIONS TO THE SOLUTION OF THE PROBLEMS

1. To successfully solve problems first, it is necessary to disassemble the relevant theoretical material in the textbook. After that, you can consider the formulae, control questions, and solving tasks in this manual.

2. Beginning with the solution of the problem, it is necessary to find out its physical content and statement of the question. As a rule, no word in the condition is not superfluous. It is necessary to identify all informative words and display the information they carry in the abbreviated record. The correct condition entry in the abbreviated form is the first and necessary step in solving the problem. Values should be expressed in units of SI only. Some non-conditional data can be identified from the tables at the end of this manual.

3. If you allow the nature of the task, you must make a drawing or a diagram explaining the essence of the task. A competent drawing makes it easier to find a solution.

4. One of the methods of solving is that first determine the formula containing the desired value and the values given in the condition. If in this formula there are unknown values, then using the auxiliary formulae, express them through known quantities. Substituting the found expressions of these unknown values into the formula of the desired value, we obtain the formula for the general solution of the problem. Many physical problems are solved with the help of conservation laws (momentum, angular momentum, energy, charge, etc.). But let us remind you that every physical law is true only if certain conditions are fulfilled. Therefore, it is worth checking whether it is possible to apply one or another law in the conditions of this task.

5. To solve problems must be in the general form, that is, to express the desired value in the literal notation of the quantities that are given in the condition. In this way, the calculation of intermediate variables is avoided.

6. After obtaining a solution in general terms, it is necessary to analyze it, to make sure that the result obtained has units of measurement of the desired value (see examples 1.4, 1.8 etc.). An incorrect unit of measurement indicates a false solution.

In the appendix to the manual, units of physical quantities are given and their connection with the basic units (in SI - meter, kilogram, second, ampere, kelvin, kan-case).

7. The calculation of the desired value must be carried out using the rules of action with approximate numbers (see appendix "On approximate calculations"). When performing numerical calculations, one must take into account the degree of accuracy of the given task. A common mistake is when the final numerical result obtained with the calculator has an accuracy that exceeds the accuracy of the output data.

In the manual, all values in the conditions of tasks are expressed, as a rule, from the exaction to three significant digits. If any number contains one or two significant digits, this means that the next two or one significant digits are zeros, which are omitted for the purpose of simplifying the record. For example, the numbers 0,1; 4; 16 should be taken at 0,100; 4.00; 16.0 etc.

Consequently, the answer must also be calculated with up to three significant digits. The numerical result should be recorded as a decimal fraction with one significant digit in front of the comma to the corresponding degree of ten. For example, instead of 3520 it is necessary to write $3,52 \cdot 10^3$ instead of 0,00129 to write $1,29 \cdot 10^{-3}$,etc.

8. After obtaining a numerical result it is necessary to estimate its likelihood. Such an assessment sometimes helps to identify an error. For example, the velocity of a particle cannot exceed the speed of light, or the charge of a particle cannot be less than the charge of an electron, etc**.**

3. THE FUMDAMENTAL LAWS AND FORMULAE OF CLASSICAL MECHANICS

3.1. Kinematics of material point (particle)

- The material point position in the space is given by the radius-vector

$$\boldsymbol{r} = x\boldsymbol{i} + y\boldsymbol{j} + z\boldsymbol{k},$$

where $\boldsymbol{i}$, $\boldsymbol{j}$, $\boldsymbol{k}$ are unit vectors (orts) of the Cartesian rectangular coordinates system; x, y, z are coordinates of the point.

- Radius-vector modulus $r = \sqrt{x^2 + y^2 + z^2}$.

- Displacement vector

$$\Delta \boldsymbol{r} = \boldsymbol{r}_2 - \boldsymbol{r}_1,$$

where $\boldsymbol{r}_2$ and $\boldsymbol{r}_1$ are the particle radiuses-vectors which correspond to the points of the originate and end of motion.

- An average and an instantaneous velocity vector

$$\langle \boldsymbol{\upsilon} \rangle = \frac{\Delta \boldsymbol{r}}{\Delta t}, \ \upsilon(t) \lim_{\Delta t \to 0} = \frac{\Delta \upsilon}{\Delta t} = \frac{dr}{dt},$$

where $\Delta \boldsymbol{r}$ is the displacement vector of the particle during the time interval Δt

$$\boldsymbol{\upsilon} = \upsilon_x\boldsymbol{i} + \upsilon_y\boldsymbol{j} + \upsilon_z\boldsymbol{k},$$

$$\upsilon_x = \frac{dx}{dt}; \ \upsilon_y = \frac{dy}{dt}; \ \upsilon_z = \frac{dz}{dt}$$

are the instantaneous velocity vector projections on the coordinate axes.

- Modulus of the instantaneous velocity vector

$$\upsilon = \sqrt{\upsilon_x^2 + \upsilon_y^2 + \upsilon_z^2} .$$

- Path passed by the particle

$$s = \int_{t_1}^{t_2} \upsilon dt .$$

- The average and instantaneous acceleration vectors

$$\langle \boldsymbol{a} \rangle = \frac{\Delta \boldsymbol{\upsilon}}{\Delta t},$$

$$\boldsymbol{a} = \frac{d\boldsymbol{\upsilon}}{dt},$$

where

$$\boldsymbol{a} = a_x\boldsymbol{i} + a_y\boldsymbol{j} + a_z\boldsymbol{k};$$

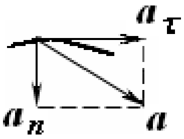
$$a_x = \frac{d\upsilon_x}{dt}, \ a_y = \frac{d\upsilon_y}{dt}; \ a_z = \frac{d\upsilon_z}{dt}$$

are the instantaneous acceleration vector projections on the coordinates axes.

- Modulus of the instantaneous acceleration vector

$$a = \sqrt{a_x^2 + a_y^2 + a_z^2}\,.$$

- Total acceleration in a curvilinear motion



$$\boldsymbol{a} = \boldsymbol{a_n} + \boldsymbol{a}_\tau,$$

where $\boldsymbol{a}_n$ is normal, and $\boldsymbol{a}_\tau$ is tangential acceleration components. Modules of these components and of the total acceleration

$$a_n = \frac{\upsilon^2}{R};\ a_\tau = \frac{d\upsilon}{dt};\ a = \sqrt{a_n^2 + a_\tau^2}\,,$$

where *R* is a trajectory radius of curvature in given point.

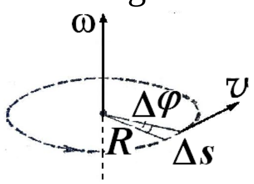
- Path and velocity in the rectilinear uniformly variable motion

$$s = \upsilon_0 t \pm \frac{at^2}{2}; \upsilon = \upsilon_0 \pm at; \upsilon^2 - \upsilon_0^2 = \pm 2as,$$

where υ_0 is the original velocity.

3.2. Kinematics of the rigid body rotation around a nonmoving axis

- An average and an instantaneous angular velocity



$$\langle\omega\rangle = \frac{\Delta\varphi}{\Delta t},\ \omega = \frac{d\varphi}{dt},$$

where Δφ is an angle of rotation.

- Angular acceleration

$$\varepsilon = \frac{d\omega}{dt}.$$

- Angular velocity for the *uniform* rotation

$$\omega = \frac{\varphi}{t} = \frac{2\pi}{T} = 2\pi n,$$

where *T* is a rotation period, *n* is a rotation frequency (*n* = *N*/*t*, where *N* is revolutions number performed during the time interval *t*).

- Angle of rotation, and angular velocity in a *uniformly variable* rotation

$$\varphi = \omega_0 t \pm \frac{\varepsilon t^2}{2};\ \omega = \omega_0 \pm \varepsilon t,\ \omega^2 - \omega_0^2 = \pm 2\varepsilon\varphi.$$

- Connection between linear and angular quantities:

$$s = R\varphi,\ \upsilon = \omega R, a_\tau = \varepsilon R, a_n = \omega^2 R,\ a = R\sqrt{\varepsilon^2 + \omega^4}\,.$$

3.3. Dynamics of the material point and translational motion of the rigid body

- The first Newton’s law:

Such frame systems exist in which body noninteracting with other bodies moves rectilinearly and uniformly; *such systems are called the inertial frame systems.*

- The momentum of the material point

$$\boldsymbol{p} = m\boldsymbol{\upsilon},$$

where m is a point mass, and

$$p_x = m\upsilon_x,\ p_y = m\upsilon_y,\ p_z = m\upsilon_z.$$

are the particle momentum projections on the coordinates axes.

- The second Newton's law (the fundamental law or motion equation of the material point in the Newton-Galilean mechanics)

$$\boldsymbol{F} = m\boldsymbol{a} = m\frac{d\boldsymbol{\upsilon}}{dt} = \frac{d\boldsymbol{p}}{dt},$$

where $\boldsymbol{F}$ is a resultant force acting on the material point. This equation is valid in the inertial frame reference.

Generalization of the second Newton's law on the noninertial frame references

$$\boldsymbol{F} = m\boldsymbol{a} + \boldsymbol{F}_{in},$$

where

$$\boldsymbol{F}_{in} = -m\boldsymbol{a}_0$$

is a force of inertia, and $\boldsymbol{a}_0$ is an acceleration of the frame system.

- The third Newton's law:

Two material points interact one with another with forces. which are equal in the value, opposite in the direction, which lie on the same straight-line and have the same physical nature.

- The radius-vector $\boldsymbol{r}_c$ of the particles system center of inertia

$$\boldsymbol{r}_c = \frac{\sum_{i=1}^{n} m_i \cdot \boldsymbol{r}_i}{m},$$

where m_i and $\boldsymbol{r}_i$ are the mass and radius-vector of the particle with number "*i*", $\sum_{i=1}^{n} m_i$ is the total system mass.

- The particles system center of inertia the velocity $\boldsymbol{\upsilon}_c$

$$\boldsymbol{\upsilon}_c = \frac{\sum_{i=1}^{n} m_i \cdot \boldsymbol{\upsilon}_i}{m},$$

where $\boldsymbol{\upsilon}_i$ is a particle velocity with number "*i*".

- Particles system momentum

$$\boldsymbol{p} = \sum_{i=1}^{n} m_i\boldsymbol{\upsilon}_i = m\boldsymbol{\upsilon}_c.$$

- The center of inertia motion law

$$\boldsymbol{F} = m\frac{d^2\boldsymbol{r}_c}{d\boldsymbol{t}^2},$$

where $\boldsymbol{F}$ is the resultant vector of the external forces.

3.4. Macroscopic forces considered in mechanics

- Force of the gravitation interaction (universal gravitation law):

$$F = G\frac{m_1 m_2}{r^2},$$

where F is a force of the attraction of the particles with masses m_1 andi m_2 disposed one relatively another at the distance r, G is a universal gravitational constant;

- if a body with mass m is under the action of the force gravity only

$$\boldsymbol{P} = m\boldsymbol{g},$$

where $\boldsymbol{P}$ is the force which acts at the body, and $\boldsymbol{g}$ is an acceleration of gravity;

- elasticity force (Hook's law) for a longitudinal tension or compression

$$F_x = -kx,$$
$$\sigma = \varepsilon E,$$

where F_x is a projection of the elasticity force on the axis Ox, k is a string elasticity coefficient (in the case of the spring it is rigidity), x is a longitudinal deformation value; $\sigma = F_x / S$ is a normal stress, S is the square of the body cross-section which undergo to deformation, $\varepsilon = x/l$ is a relative deformation, l is a body initial length, E is Young-modulus.

- force of sliding friction

$$F_{fr} = \mu N,$$

where μ is a sliding friction coefficient; N is a normal tension force (pressing force).

3.5. Rotation dynamics of a material point and rigid body around a fixed axis

- A material point angular momentum $\boldsymbol{L}$ relatively a point

$$\boldsymbol{L} = \boldsymbol{r} \times \boldsymbol{p},$$

where $\boldsymbol{r}$ is a particle radius-vector in given moment, $\boldsymbol{p}$ is its momentum.

- A force moment $\boldsymbol{M}$ relatively a point

$$\boldsymbol{M} = \boldsymbol{r} \times \boldsymbol{F}.$$

- A moments equation

$$\frac{d\boldsymbol{L}}{dt} = \boldsymbol{M}.$$

- Angular momentum of the particle moving along a rectilinear trajectory,

$$L_z = m\upsilon l,$$

where l is an arm of the momentum (it is the shortest distance from the rotation axis till the momentum direction);

- Angular momentum of the particle moving along a circle with radius r,

$$L_z = m\upsilon r.$$

- The material point moment of inertia relative the axis Oz

$$J = mr^2,$$

where m is the mass of the material point and r is its distance from the axis.

- A rigid body moment of inertia relative the axis Oz

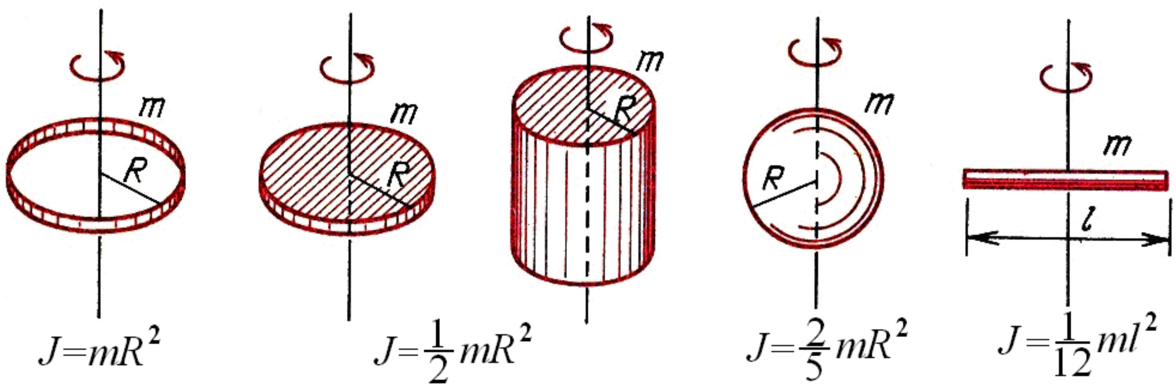
$$J = \sum_{i=1}^{n} m_i \cdot r_i^2,$$

where r_i is a distance of the mass element Δm_i from the axis Oz. In the case of the continuous distribution masses

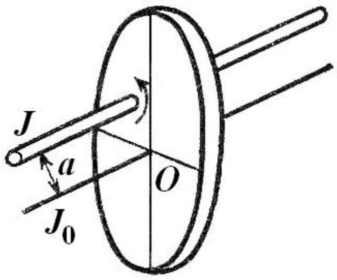
$$J_z = \int r^2 dm.$$

- Moments of inertia of regular geometrical shape a some bodies:

Body	*Axis relatively which the moment of inertia is defined*	*Moment of inertia*
Homogeneous thin rod with mass m and length l	Pass through the rod center of inertia perpendicular to the rod	$\frac{1}{12}ml^2$
	Pass through the end of the rod perpendicular to the rod	$\frac{1}{3}ml^2$
Thin ring, hoop, pipe, flywheel with mass, distributed along the rim with radius R and mass m	Symmetry axis	mR^2
Homogeneous circular disk or cylinder with radius R and mass m	Symmetry axis	$\frac{1}{2}mR^2$
Homogeneous sphere with radius R and mass m	Pass through the sphere center	$\frac{2}{5}mR^2$



- Body moment of inertia relative the arbitrary axis Oz which is parallel to the axis passing through the body center of inertia (parallel axis theorem or Huygens-Steiner theorem)



$$J_z = J_0 + ma^2,$$

where J_0 is the body moment of inertia– relative the axis which passes through its center of inertia, J is the body moment of inertia relative the axis which is parallel to the axis passing through the body center of inertia, m is the body mass a is a distance between the axes.

- Force moment (rotational moment) relative the rotation axis Oz

$$M_z = F_{\perp}\, l,$$

where $F_{\perp}$ is a force projection at the plane which is perpendicular to the axis Oz, l is an arm of the force (it is the shortest distance from the rotation axis till the line of action of a force).

- Angular momentum of the rigid relative a fixed rotation axis Oz

$$L_z = J_z \omega,$$

where J_z is a body moment of inertia relative a rotation axis, ω is body angular velocity.

- Dynamics equation of the rigid body rotational motion relatively fixed axis

$$M_z = \frac{dL_z}{dt} = J_z \frac{d\omega}{dt}, \text{ or } M_z = J_z \varepsilon,$$

where M_z is a resultant angular momentum relatively the axis Oz of the external forces acting at the body; ε is an angular acceleration, J_z is the body moment of inertia relatively rotation axis.

3.6. Conservation laws

- Momentum conservation law for closed system

$$\boldsymbol{p} = \sum_{i=1}^{n} m_i \boldsymbol{v}_i = \overrightarrow{\text{const}},$$

where $\boldsymbol{p}_i = m_i \boldsymbol{v}_i$ is a particle momentum with number "i".

- Variation of the momentum of the particles system which is being under the action of the external

$$d\boldsymbol{p} = \boldsymbol{F} \cdot dt,$$

or for finite time interval from t_1 till t_2.

$$\boldsymbol{p}_2 - \boldsymbol{p}_1 = \int_{t_1}^{t_2} \boldsymbol{F}(t) \cdot dt.$$

- Elementary work ΔA_i of the alternative force $\boldsymbol{F}(\boldsymbol{r}_i)$ at the elementary displacement $\Delta\boldsymbol{r}_i$

$$\Delta A_i = \boldsymbol{F}(\boldsymbol{r}_i)\cdot\Delta\boldsymbol{r}_i = F(\boldsymbol{r}_i)\cdot|\Delta\boldsymbol{r}_i|\cdot\cos\alpha_i \approx F_s(\boldsymbol{r}_i)\cdot\Delta s_i,$$

where α_i is the angle between the force vector and vector of the elementary displacement, Δs_i is a length of the trajectory element corresponding to the displacement $\Delta\boldsymbol{r}_i$.

- Work of the alternative work at the finite displacement or finite part of path

$$A = \lim_{|\Delta r_i|\to 0}\sum_i \boldsymbol{F}(\boldsymbol{r}_i)\cdot\Delta\boldsymbol{r}_i = \int_l \boldsymbol{F}(\boldsymbol{r})\cdot d\boldsymbol{r};$$

$$A = \lim_{\Delta s_i\to 0}\sum_i F_s(\boldsymbol{r}_i)\cdot\Delta s_i = \int_l F_s(\boldsymbol{r})\cdot ds,$$

where l is the curve along which the particle moves.

- Work performed when the particle moves in the centrosymmetrical Worth gravity field

$$A = \frac{GMm}{r_2} - \frac{GMm}{r_1},$$

where *M* is the mass of the Worth, *m* is the particle mass, r_1 and r_2 originate and final particle distances from the Worth center.

- Work performed when the particle moves in the homogeneous Worth gravity field

$$A = mg_0(h_1 - h_2),$$

where $g_0 = \dfrac{GM}{r_0}$ is an acceleration of gravity near the Worth surface, r_0 is the Worth radius, $h_1 = r_1 - r_0,\ h_2 = r_2 - r_0$ and the assumption that $h_1 \ll r_0; h_2 \ll r_2$ is made here.

- Work performed by the elasticity forces when the string deformation occurs

$$A = \frac{kx_1^2}{2} - \frac{kx_2^2}{2},$$

where x_1 and x_2 are the initial and final deformation value of the string.

- Work performed by the forces of the sliding friction

$$A = -F_{fr}\cdot S,$$

where F_{fr} is a modulus of the friction force, and S is a path which is passed by the body when mentioned force acts.

Concept of the conservative force. *The force is called a conservative if a work of this force when a particle displaces along any closed counter is equal to zero, or, if* *a work performed by this force when a particle displaces from one of the space point into another does not depend on the particle trajectory form*.

- Instantaneous power

$$N = \frac{dA}{dt} = F\upsilon\cos\alpha .$$

- Material point kinetic energy

$$T = \frac{m\upsilon_c^2}{2},$$

or

$$T = \frac{p^2}{2m}.$$

- Kinetic energy of the material point system

$$T = \sum_{i=1}^{n} \frac{m_i\upsilon_i^2}{2} = \frac{m\upsilon_c^2}{2} + \sum_{i=1}^{n} \frac{m_i\upsilon_i'^2}{2},$$

where $\upsilon_i' = \upsilon_i - \upsilon_c$ is a velocity of the particle with number "*i*" relatively the center of inertia of the particles system.

- Kinetic energy of the rigid body rotating relatively fixed axis

$$T = \frac{J\omega^2}{2}.$$

- Kinetic energy of the rigid body performing a plane motion

$$T = \frac{m\upsilon_c^2}{2} + \frac{J\omega^2}{2}.$$

- Theorem on the kinetic energy

$$T_2 - T_1 = A,$$

where T_1 and T_2 are the kinetic energy of the particles system in the origin and final of motion, and A is a work both the internal and external forces as well.

- Potential energy:

– potential energy of a material point in the centrosymmetrical Worth gravity field

$$\Pi = -G\frac{Mm}{r},$$

if the origin of the potential energy is chosen in infinity,

– potential energy of a material point in the homogeneous. Worth gravity field

$$\Pi = mgh$$

under the assumption $h << r_0$.

– potential energy of an elastic reformatted string

$$\Pi = \frac{kx^2}{2},$$

It is considered that the potential energy of the nodeformatted string is equal to zero.

- Connection between the potential energy and conservative force

$$F_x = -\frac{\partial \Pi}{\partial x}; F_y = -\frac{\partial \Pi}{\partial y}; F_z = -\frac{\partial \Pi}{\partial z},$$

or

$$\boldsymbol{F} = -\left(\boldsymbol{i}\frac{\partial \Pi}{\partial x}\right) + \left(\boldsymbol{j}\frac{\partial \Pi}{\partial y}\right) + \left(\boldsymbol{k}\frac{\partial \Pi}{\partial z}\right).$$

In other words, *the conservative force is a gradient of the potential energy*

- Total potential energy of the material points system.

$$\Pi = \Pi_{\text{int}} + \Pi_{ext},$$

where Π_{int} is the potential energy connected with interaction of the material points between themselves, and Π_{ext} is the potential energy connected with their interaction with external bodies.

- Total mechanical energy E of the conservative system

$$E = T + \Pi.$$

- Energy conservation law in mechanics

$$E = constant$$

in the conservative systems.

- Variation of the material point system mechanical energy being under the action of the nonconservative forces

$$E_2 - E_1 = A;$$

where E_1 and E_2 are the total energy of the system in the origin and end of the process, and A is the work of both internal and external nonconservative forces.

- Application of the conservation laws of the mechanical energy and momentum to the elastic and inelastic spheres collisions:
  – central absolute elastic spheres collision

$$u_{x_1} = \frac{2m_2\upsilon_{x_2} + (m_1 - m_2)\upsilon_{x_1}}{m_1 + m_2};$$

$$u_{x_2} = \frac{2m_2\upsilon_{x_1} + (m_1 - m_2)\upsilon_{x_2}}{m_1 + m_2},$$

where m_1 and m_2 are the particles masses, υ_{x_1} and υ_{x_2} are the spheres velocities projections on the axis *oX* before the collision, u_{x_1} and u_{x_2} are the spheres velocities projections on the same axis after collision;

– absolute inelastic spheres collision

$$\boldsymbol{u} = \frac{m_1\boldsymbol{v}_1 + m_2\boldsymbol{v}_2}{m_1 + m_2}.$$

- Angular momentum conservation law for closed system and system which is being under the central forces action.

$$\boldsymbol{L} = \sum_{i=1}^{n} \boldsymbol{L}_i = \sum_{i=1}^{n} \boldsymbol{r}_i \times \boldsymbol{p}_i = \overrightarrow{\text{const}}.$$

- Variation of the system angular momentum if it is unclosed or if it is under the action of the forces which are noncentral

$$d\boldsymbol{L} = \boldsymbol{M} \cdot dt,$$

or for finite time interval from t_1 till t_2

$$\boldsymbol{L}_2 - \boldsymbol{L}_1 = \int_{t_q}^{t_2} \boldsymbol{M}(t) \cdot dt,$$

where $\boldsymbol{M}$ is a main vector of external forces moment acting on the considered system.

3.7. Elements of the relativity theory

- Galilean transformation of the coordinates and time

$$\boldsymbol{r}' = \boldsymbol{r} - \boldsymbol{V} \cdot t,$$
$$t' = t,$$

where prime relates to the moving coordinates system. If in the initial moment of time origins and coordinates axes both systems coincide and then one from them begin to move in the positive direction of the axis oX with the velocity $\boldsymbol{V}(V_x = V, V_x = V, V_x = 0)$, we have

$$x' = x - V \cdot t;$$
$$y' = y; z' = z;$$
$$t' = t.$$

- The velocity addition law in Newton-Galilean mechanics

$$\boldsymbol{v} = \boldsymbol{v}' + \boldsymbol{V}.$$

- Acceleration vector

$$\boldsymbol{a}' = \boldsymbol{a}.$$

- Kinematical invariants of Galilean transformations:

– duration of an event

$$\Delta t' = \Delta t;$$

– a distance between the points in the space

$$l' = l;$$

– a vector of the relative velocity

$$\boldsymbol{v}_2' - \boldsymbol{v}_1 = \boldsymbol{v}_2' - \boldsymbol{v}_1' = \boldsymbol{V};$$

- Dynamical invariants of Galilean transformations:

– a particle mass

$$m' = m;$$

– a force vector in Newton-Galilean mechanics

$$\boldsymbol{F}' = \boldsymbol{F};$$

– the motion law in Newton-Galilean mechanics

$$\boldsymbol{F}' = m' \cdot \boldsymbol{a}';$$
$$\boldsymbol{F} = m \cdot \boldsymbol{a},$$

or, *in all inertial frame references mechanics laws have the same form*. *It is the mechanic relativity principle, or Galilean relativity principle*

- Elements of relativistic mechanics

– Einstein's postulates:

a) in all inertial frame references mechanics laws have the same form (it is the special relativity principle, or Einstein's relativity principle);

b) the velocity of light in free space does not depend on the velocity source of light and is constant in all inertial frame systems.

– Lorentz's transformations of the coordinates and time

$$x' = \frac{x - V \cdot t}{\sqrt{1 - \frac{V^2}{c^2}}};$$
$$y' = y;\ z' = z;$$
$$t' = \frac{t - x \cdot V / c^2}{\sqrt{1 - \frac{V^2}{c^2}}}.,$$

where $c = 3 \cdot 10^8 m/\sec$ is velocity of light in free space.

- Kinematic effects of Lorentz's transformations

– relativistic shrinkage of the bodies longitudinal sizes

$$l = l_0 \cdot \sqrt{1 - \frac{V^2}{c^2}},$$

where l_0 is a body longitudinal size (length of rod) in the frame system in which the body is in the rest,

– relativistic time dilation

$$\Delta t' = \frac{\Delta t}{\sqrt{1 - \frac{V^2}{c^2}}},$$

where Δt is a duration of the event that begins and ends at the same point in the reference frame in which the clock is at rest.

– relativistic law of velocities addition

$$\upsilon_x = \frac{\upsilon'_x + V}{1 + \frac{\upsilon'_x \cdot V}{c^2}}; \upsilon_y = \upsilon'_y \frac{\sqrt{1 - \frac{V^2}{c^2}}}{+ \frac{\upsilon'_x \cdot V}{c^2}}; \ \upsilon_z = \upsilon'_z \frac{\sqrt{1 - \frac{V^2}{c^2}}}{+ \frac{\upsilon'_x \cdot V}{c^2}}.$$

- Kinematic invariants of Lorentz's transformation:

– velocity of light in free space: $c = 3 \cdot 10^8 m/\sec$;

– interval between the events

$$ds^2 = c^2 \cdot dt^2 - dr^2,$$

where dt is the time distance between the events, and dl is the space distance between the points in which the events take place.

– object selftime

$$d\tau = \frac{ds}{c} = \sqrt{1 - \frac{V^2}{c^2}} \cdot dt,$$

where dt is a time distance which is measured in the frame system relative of which the object moves with the velocity V.

- Elements of relativistic dynamics:

– relativistic momentum

$$\boldsymbol{p} = \frac{m\boldsymbol{\upsilon}}{\sqrt{1 - \frac{\boldsymbol{\upsilon}^2}{c^2}}},$$

where m is object mass.

– relativistic motion law

$$\boldsymbol{F} = \frac{d\boldsymbol{p}}{dt} = m \cdot \frac{d}{dt} \frac{\boldsymbol{\upsilon}}{\sqrt{1 - \frac{\boldsymbol{\upsilon}^2}{c^2}}}.$$

– total energy of a relativistic particle

$$E = \frac{mc^2}{\sqrt{1 - \frac{\boldsymbol{\upsilon}^2}{c^2}}};$$

– selfenergy of a relativistic particle

$$E_0 = mc^2.$$

- Kinetic energy of a relativistic particle

$$T = E - E_0 = mc^2\left(\frac{1}{\sqrt{1-\frac{\boldsymbol{v}^2}{c^2}}} - 1\right).$$

- Lorentz's transformations of the momentum and energy

$$p'_x = \frac{p_x - \left(V/c^2\right)\cdot E}{\sqrt{1-\frac{V^2}{c^2}}};$$

$$p'_y = p_y;\ p'_z = p_z;$$

$$E' = \frac{E - V\cdot p_x}{\sqrt{1-\frac{V^2}{c^2}}},$$

- Lorentz's transformations of the force
  - Transformation of a projection longitudinal in relative to the vector $\boldsymbol{V}$

$$F_x = F_x{}'$$

  - Transformation of the projections transversal in relative to the vector $\boldsymbol{V}$

$$F_y = \frac{F'_y}{\sqrt{1-\frac{V^2}{c^2}}};\ F_z = \frac{F'_z}{\sqrt{1-\frac{V^2}{c^2}}}$$

- Binding energy of a relativistic system

$$E_b = \left(m - \sum_{i=1}^{n} m_i\right)\cdot c^2,$$

where m is the mass of coupled system, and m_1 is the mass of the particle with number "i".

- Mass defect of a relativistic system

$$\Delta m = \left(m - \sum_{i=1}^{n} m_i\right) = \frac{E_b}{c^2}.$$

- Connection between the particle total energy, its velocity vector and momentum vector

$$\boldsymbol{p} = \frac{E}{c^2} \cdot \boldsymbol{\upsilon}$$

and

$$\boldsymbol{p} = \frac{E}{c} \cdot \boldsymbol{n}$$

for a massless particle, where n is a unit momentum vector.

- Invariant relationship between a momentum vector. Total energy and particle mass

$$p^2 - \frac{E^2}{c^2} = -(mc)^2 .$$

4. THE PROBLEMS FOR THE INDEPENDENT SOLVING

OPTION 1

1. Initial particle velocity vector is $\boldsymbol{\upsilon}_1 = l\boldsymbol{i} + 3\boldsymbol{j} + 4\boldsymbol{k}$ (m/s), and finite vector is $\boldsymbol{\upsilon}_2 = 2\boldsymbol{i} + 4\boldsymbol{j} + 6\boldsymbol{k}$ (m/s). Define: a) the velocity vector increment $\Delta\boldsymbol{\upsilon}$; b) the modulus of velocity vector increment $|\Delta\boldsymbol{\upsilon}|$; c) increment of the velocity vector modulus $\Delta|\boldsymbol{\upsilon}|$.

2. The motion of two material points is described by the equations $x_1(t) = A_1 + B_1 t + C_t t^2$, $x_2(t) = A_2 + B_2 t + C_2 t^2$, where $A_1 = 20m$; $A_2 = 2m$; $B_1 = B_2 = 20 m/s$; $C_1 = 4 m/s^2$; $C_2 = 0{,}5 m/s^2$. At what moment of time t the speeds of these material points will be the same? Define speed υ_1 and υ_2 and accelerates modulus a_1 and a_2 of given material points in found moment of time.

3. The wheel rotates with a constant angular acceleration $\varepsilon = 3 rad/s^2$. Determine the radius of the wheel r, if later $t = 1s$ after the start of the movement, the total acceleration a of the point on the rim of the wheel is $7{,}5 m/s^2$.

4. A stone with mass $m = 0{,}5kg$ is thrown horizontally with initial velocity $\upsilon_0 = 8 m/s$. Determine: 1) the stone momentum modulus p at the end of the fifth second from the motion beginning; 2) the angle which the momentum vector at noted moment of time forms with the initial velocity vector.

5. A thin, homogeneous rod of length $l = 50cm$ and with mass $m = 400g$ rotates with an angular acceleration $\varepsilon = 3 rad/s^2$ relative to the axis which passes perpendicularly to the rod through its center. Determine the torque M.

6. A hollow, thin-walled cylinder rolls along the horizontal section of the road with a velocity $\upsilon = 1{,}5 m/s$. Determine the path S that it will climb upward due to kinetic energy, if the slope of the trajectory is equal to $5m$ for every $100m$ of the path.

7. Two relativistic particles move towards each other along one line with velocities $\upsilon_1 = 0{,}6c$ and $\upsilon_2 = 0{,}9c$. Determine their relative velocity υ.

OPTION 2

1. The radius-vector of a material point variates over time according to the law $\boldsymbol{r}(t) = 4t^2\boldsymbol{i} + 3t\boldsymbol{j} + 2\boldsymbol{k}$ (m). Determine: 1) the speed of the material point $\upsilon(t)$; 2) acceleration modulus of the material point $a(t)$; 3) the speed of the material point at the moment of time $t = 2s$ from the start of motion.

2. An armature of an electric motor which has the rotation frequency $n = 50s^{-1}$ after the current turning-off, out made $N = 628$ turns and stopped. Determine the angular acceleration of the armature.

3. To the spring balance a block is suspended. Through the block, the filament has been thrown up, the ends of which are loaded with masses $m_1 = 1{,}5kg$ and $m_2 = 3{,}0kg$. Define the indications of the balance during the movement. The weight of the block and filament is neglected.

4. A bullet with mass $m = 10g$ flying with the velocity $\upsilon_0 = 500m/s$ hits in the board with a thickness $d = 3sm$ situated vertically and passes through it during the time interval $\Delta t = 20m/s$ Determine the average resistance force $\langle F \rangle$ acting at the bullet for the time interval when it passes through the board.

5. A homogeneous disk with mass m and with shell with external radius R and internal radius r rolls without slipping along an inclined plane, forming an angle α with the horizont. Determine the linear acceleration a of the disk center.

6. The flywheel with the moment of inertia $J = 40kg \cdot m^2$ is under the action of force moment $M = 20N \cdot m$ performs a uniformly variable rotation being in the rest state from the beginning, Determine the kinetic energy T that the flywheel acquires through $t = 10s$ after the motion start.

7. Lifetime of the muon, which is in a state of rest, $\tau_0 - = 2{,}2\mu s$. From the birth point to the detector registering its decay, the muon flew the distance $l = 6km$. Determine the velocity υ (in the parts of speed of light in free space c by which the muon possesses in the motion process).

OPTION 3

1. The material point moves rectilinearly and modulus of its acceleration increases linearly, and during the first $t = 10s$ reaches the value $a = 5m/s^2$. Define at the end of the tenth second: 1) the speed of the material point υ; 2) the path passed by the material point during this time.

2. The car's wheel rotates uniformly decelerate. In moment of time $t = 2$ minutes from the motion start it variated the rotation frequency from $240\min^{-1}$ to $60\min^{-1}$. Determine: 1) angular acceleration ε of the wheel; 2) the number of full turns N made by the wheel during the noticed time.

3. A bullet with mass $m = 10g$ flying horizontally with the speed $\upsilon = 0{,}5km/s$, falls into a box with sand of mass $M = 6kg$ suspended on the cable of length $l = 1m$ and gets stuck in it. Determine the height h, on which such a ballistic pendulum will climb, deflecting after impact.

4. A stone with mass $m = 0{,}5kg$ is thrown under the angle with horizont $\alpha = 30^{\circ}$ and with the initial velocity $\upsilon_0 = 40 m/s$. Neglecting by a resistance determine: 1) the modulus difference of the momentums vectors $|\Delta \boldsymbol{p}| = |\boldsymbol{p}_2 - \boldsymbol{p}_1|$, where $\boldsymbol{p}_1$ is the momentum vector in the initial point of the stone trajectory and $\boldsymbol{p}_2$ is the momentum vector in the highest point of the stone trajectory; 2) the modulus difference of the momentums vectors in the initial point of stone trajectory and its ending point; 3) the modulus difference of the momentums vectors in the initial and ending points of stone trajectory.

5. On a body with mass m rotating relative its symmetry axis acts a force F, which in all described cases has the same arm. Determine an angular acceleration of the body at any moment of time if it is: 1) a solid homogeneous cylinder with radius r; 2) a hollow cylinder with radius r; 3) a solid homogeneous sphere with radius r; 4) a thin homogeneous rod with length l; 5) a thin homogeneous rod with length l if the rotation occurs relative one of its end.

6. The flywheel begins to rotate from a rest state with a constant angular acceleration $\varepsilon = 0{,}4 rad/s^2$. Determine the kinetic energy T of the flywheel at the time $t_2 = 25s$ after the start of the movement, if, after $t_1 = 10s$ after the start of the movement the flywheel angular momentum relative the rotation axis is $L_z = 60 kg \cdot m/s$.

7. Determine the energy of rest E_0 (self-energy) for the following particles: 1) electron; 2) proton; 3) alpha particle. Represent the answer in terms of joule and megaelectron-volt. Compare obtained results with kinetic energy T of these particles moving with the velocity $\upsilon = 3 \cdot 10^6 m/s$, calculated by the nonrelativistic formula.

OPTION 4

1. The equation of the body rectilinear motion has the form $x(t) = At + Bt^2 + Ct^3$ ($A = 2 m/s; B = 3 m/s^2; C = 4 m/s^3$). Give expressions for speed and acceleration modulus. Define for the moment of time $t = 2s$ after the movement start: 1) the path passed by the body; 2) its speed; 3) its acceleration.

2. The material point moves along a circle with a radius $r = 15 sm$ with constant tangential acceleration a_τ. At the end of the fourth turn after the start of motion, the linear velocity of the material point becomes $\upsilon = 15 sm/s$. Determine the normal acceleration of the material point through $t = 16s$ after the start of motion.

3. A bullet with mass $m = 10g$ flying horizontally with the speed $\upsilon = 0{,}5 km/s$, falls into a box with sand of mass $M = 1{,}5kg$ suspended on the cable of length $l = 1m$ and stucks in it. Determine the speed which the box will possess as a result of collision.

4. A stone with mass $m = 4kg$ flying with a velocity $\upsilon = 25 m/s$ under the angle $\alpha = 45°$ to the normal of the wall collides with given wall. Friction coefficient of the stone material and wall is $\mu = 0{,}3$. The time of collision is $\Delta t = 2ms$. Determine: 1) momentum modulus $|\Delta \boldsymbol{p}|$ transmitted by the stone to the wall when the collision happens; 2) the average value of the friction force $\langle F_{fr} \rangle$ during the collision duration; 3) the average value of the normal reaction force $\langle F_n \rangle$ during the collision duration.

5. A ball of radius $R = 10cm$ and with a mass $m = 5kg$ rotates around the axis of symmetry according to motion law $\varphi = A + Bt^2 + Ct^3$ ($B = 2 rad/s^2$; $C = -0{,}5 rad/s^3$). Determine the moment of the rotating force M for the moment of time $t = 3s$ from the start of motion.

6. A horizontal platform with a mass $m = 25kg$ and a radius $R = 0{,}8m$ rotates making $n_1 = 18$ rotations per minute. There is a man in the center of the platform which holds dumbbells on his elongated hands. Considering the platform as a homogeneous disk, determine the frequency of rotation of the platform n_2, if a man, which has lowered his hands, will reduce his moment of inertia from= $J_1 = 3{,}5 kg \cdot m^2$ to $J_2 = 1 kg \cdot m^2$.

7. Determine a kinetical energy T of the electron moving with the velocity $\upsilon = 0{,}6c$ and compare it with one calculated by the nonrelativistic formula.

OPTION 5

1. The stone was thrown horizontally from a tower. Latter $t = 2s$ after of throw the stone fall on the worth at a distance $s = 40m$ from the tower base. Determine the initial speed υ_0 and finite v speed of the stone.

2. A disk of radius $R = 10 sm$ rotates around the fixed axis so that the rotation angle dependence from the time has the form $\varphi = A + Bt + Ct^2 + Dt^3$ ($B = 1 rad/s; C = 1 rad/s^2; D = 1 rad/s^3;$). For points on the rim at the end of the second after the start of motion of the disk determine:

1) the tangential acceleration a_τ; 2) the normal acceleration a_τ; 3) the total acceleration a_{tot}.

3. The material point with mass $m = 1kg$, which moves uniformly, describes a quarter of a circle with radius $r = 1{,}2m$ during the time interval $\Delta t = 2s$. Determine the variation of the the material point momentum $|\Delta \boldsymbol{p}|$.

4. A body with mass m slides along an inclined plane from the beginning upward the plane and then down it with an accelerations which are equal one to

another upon the modulus. The inclination angle of the plane to horizont is α, sliding friction coefficient when the body moves along the plane is μ. Determine a value of the external additional force F acting on the body when it moves upward along the inclined plane.

5. Considering the Earth as a homogeneous sphere with density $\rho = 10^3 kg/m^3$ and with radius $r = 6{,}4 \cdot 10^6 m$ determine :1) the Earth moment of inertia relative an axis passing through its center; 2) the Earth angular momentum relative given axis; 3) the Earth angular momentum of its orbital motion considering the Earth as a material point and assuming that it uniformly rotates along the circle with radius $R = 1{,}5 \cdot 10^{11} m$.

6. There is a man in the center of a platform rotating around a vertical axis with frequency $n_1 = 30$ rotation per minute. The man moment of inertia relative to the axis of rotation is $J_1 = 1{,}2 kg \cdot m^2$, in his elongated hands there are two dumbbells with mass of every $m = 3kg$. The distance between dumbbells is $l_1 = 160 sm$. Determine the platform frequency of rotation, if the man lowers his hands and the distance between dumbbells will become $l_2 = 40 sm$.The platform is considered as a homogeneous disk with mass $m_1 = 25 kg$ and a radius $R = 1m$. The changing of the hands moment of inertia and friction presence is neglected.

7. A satellite spacecraft contains a clock synchronized before with the Earth's one The velocity of the satellite is $\upsilon_0 = 7{,}9 km/s$. Determine how the clock on the satellite will slow during $\tau_0 = 0{,}5 years$ compared to the clock of the Earth observer.

OPTION 6

1. The radius-vector of a material point variates over the time according to the law $\boldsymbol{r}(t) = At^2\boldsymbol{i} + Bt\boldsymbol{j} + C\boldsymbol{k}$, where $A = 2 m/s^2$; $B = 5 m/s$; $C = 3m$. Determine: 1) the velocity of the point $\boldsymbol{\upsilon}(t)$; 2) acceleration of the point $\boldsymbol{\upsilon}(t)$; 3) the material point speed υ at the moment of time $t = 4s$ from the beginning of the motion.

2. The disk rotates around the fixed axis so that the dependence of the rotation angle of the disk on the time is given by the equation $\varphi = At^2$ ($A = 0{,}5 rad/s^2$). Determine at the end of the second after the start of the movement: 1) the angular velocity ω of the disc; 2) angular acceleration ε of the disk; 3) tangential a_τ, normal a_n and a total acceleration a_{tot} for a point located at a distance of 80*sm* from the axis of rotation.

3. A body slips upon an inclined plane with an inclination angle α = 30 ° to the horizont. Determine the speed of the body at the end of the second from the beginning of the slip if the friction coefficient is $f = 0{,}15$.

4. A weight with mass $m = 5kg$ suspended to the copper filement with length $l = 7{,}5m$ and with the cross-section radius $r = 2{,}5mm$ being in the an equilibrium state as a result of the slight push gets some velocity υ. Determine this velocity if it is known that as a result of the push the stress in the filement becomes $\sigma = 0.01\sigma_{\max}$, where $\sigma_{\max} = 200G\,Pa.$ is supposed value of the copper ultimate strength.

5. A shaft with mass $m = 50kg$, with radius $R = 0{,}2m$ rotates uniformly with the angular velocity $\omega_0 = 15 rad/s$. Determine a number of total rotations N done by the shaft from the moment of time when a braking was engaged, if the friction coefficient between the shaft surface and the brake shoe is $\mu = 0{,}15$, and the force pressing the brake shoe against the shaft surface is $F = 200N$.

6. A planet moves along an elliptic orbit around Sun. Determine at what from noticed points of planet trajectory perihelion or apogee its kinetic energy is the largest.

7. There is a system from two photons. Every from photons has the same energy E. Determine the mass of the photons system in the following cases: 1) photons momentums have the same direction; 2) photons momentums have the opposite direction; 3) photons momentums are mutual perpendicular.

OPTION 7

1. The disk rotates around the fixed axis so that the dependence of the rotation angle on the time is given by the equation $\varphi = At^2$ j ($A = 0{,}1 rad/s^2$). Determine the total acceleration of a disk point situated on its rim at the end of the second after the start of motion, if the linear velocity of this point at this moment is $\upsilon = 0{,}4 m/s$.

2. The material point moves according to equation $x(t) = A + Bt + Ct^2 + Dt^3$ ($C = 1m/s^2; D = -0{,}2\,m/s^3$) Determine: 1) acceleration modulus of the particle at moments of time $t_1 = 2s; t_2 = 5s$; after motion start; 2) the moment of time when the acceleration projection will be turns into zero.

3. A steel wire with radius $r = 1mm$ and with mass $m = 100kg$ is suspended vertically. The ultimate strength of steel is $\sigma_{us} = 0{,}49GPa$. Determine the largest angle α at what it is possible to remove the wire from the equilibrium state in order to turning in this state the wire does not be broken.

4. A body with a mass $m = 50kg$ suspended to the rope rotates around a column situated vertically. The length of a rope is $l = 2m$, the angular velocity of the body rotation is $\omega = 25 rad/s$. Determine the angle α which the rope produced with the column when the body rotates.

5. Determine a moment of inertia I of a spherical shell relative the axis passing through the symmetry center of the shell. Mass of the shell is m, its external radius is R and its internal radius is r.

6. The total kinetic energy of a homogeneous disk moving along a horizontal surface is $T = 24 Joule$. Determine: 1) the kinetic energy T_1 of the disk center of inertia forward motion; 2) the disk kinetic energy T_2 of its rotational motion.

7. A photon rocket moves relative to the Earth at a velocity $\upsilon = 0{,}6c$. Determine what is slowed the rate of clock in a rocket from the Earth observer point of view.

OPTION 8

1. A material point motion describes by the law $\boldsymbol{r}(t) = A\sin\omega t \cdot i + B\cos\omega t \cdot j$, where $A = 5sm; B = 5sm, \omega = 20 rad/s$. Represent the trajectory of the material particle in a figure and determine its speed at the points according to the largest and to the smallest distances from the origin.

2. A disk with a radius $R = 10 sm$ rotates so that for the points lying on the rim of the disk linear velocity dependence on the time is given by the equality $\upsilon(t) = A(t)$, where $A = 0{,}3 m/s^2$. Determine the moment of time when the vector of the disk total acceleration will form the angle $\varphi = 45^\circ$ with its radius.

3 In a particles system the elastic forses. gravity forces and friction forces act, If this system is a conservative one?

4. A weight with a mass $m = 50 kg$ is suspended on the steel wire with a cross-section radius $r = 2mm$. Determine a specific elongation of the wire $\frac{\Delta l}{l}$ in the following cases: 1) the wire moves up uniformly; 2) the wire moves down uniformly; 3) the wire moves with the acceleration $a = 5 m/s^2$ directed up; 4) the wire moves with the acceleration $a = 5 m/s^2$ directed down. The mass of the wire is considered to be small in conparison with the weight one. Steel Young modulus is $E = 200 GPa$.

5. Through the unmoving block a massless nonstretchable line is thrown. To the line the weights with masses m_1 and m_2 are suspended. The block mass is m. Determine: 1) an acceleration a with which the weights move; 2) reaction force F_R of the block; 3) tension forces F_1 and F_2 of the line on the both sides of the block.

6. A sphere moving at the velocity v_1 comes into collision with unmoving sphere which has a mass in n time larger then impacting sphere mass. The collision is considered to be central and absolutely elastic. Determine what variates the velocity of the impacting sphere.

7. A rod of length l_0 and the cross-section S_0 in its proper frame system moves with the velocity υ. Determone: 1) the rod length l in the laboratory frame system; 2) the rod volume V in this system.

OPTION 9

1. A body moves rectilinearly. The time dependence of the path passed by the body is given by the relation $S = A + Bt + Ct^2 + Dt^3$, where $C = 0{,}1 m/s^2; D = 0{,}03 m/s^3$. Determine: 1) the moment of the time reading start of motion when the body acceleration will be equal to $a = 21 m/s^2$; 2) the body average acceleration $\langle a \rangle_{\Delta t}$ over the time interval according to given moment of time.

2. A disk with the radius $R = 10 sm$ rotates so that the dependence on the time of the disk rotation angle is given by the relation $\varphi = At + Bt^3$, where $A = 2 rad/s; B = 4 rad/s^3$. Determine: 1) the normal acceleration a_n at the moment of the time $t = 2s$ after the motion start for the points on the rim of the disk; 2) the tangential acceleration a_t of the same points and at the same moment of time; 3) the angle of rotation φ which corresponds to the angle $\alpha = 45^\circ$ between the total acceleration vector and vector of the normal acceleration.

3. The body with mass $m = 2kg$ is suspended to a weightless filament and moves in the vertical plane with the acceleration $a = 5 m/s^2$. Determine a filament tension if: 1) the body gets up and its acceleration vector is directed downwards; 2) the body falls down and its acceleration vector is directed downwards; 3) the body falls down and its acceleration vector is directed upward; 4) the body gets up and its acceleration vector is directed upward.

4. A pedaler moves with the acceleration $a = 0{,}2 m/s^2$ upward along a road with the inclination $0{,}02$ which is equal to $\sin\alpha = 0{,}02$ (α is an angle of the road inclination to horizont). Determine a minimal friction coefficient μ between the wheel tyre and a road.

5. The desk with mass $m = 10 kg$ and with length $l = 5m$ is situated on the bearing located in the middle of the desk. On the ends of the desk the weights with masses $m_1 = m_2 = 2kg$ are situated. The desk may be considered as thin homogeneous rod. Determine an angular acceleration ε of the desk just after removal one of the weights.

6. Towards to body of mass m moving with the velocity υ moves other body of mass M and with the velocity V. Determine what a part of the bodies total initial kinetic energy transfers into nonmechanical energy forms.

7. In accelerator with colliding beams particles move towards each other with velocity $\upsilon = 0{,}9c$ relative the laboratory. Determine: 1) the relative velocity υ_{rel} of the particles; 2) total energy T_{tot} one of the particles in the frame system connected with another one.

OPTION 10

1. The motion of a material point is given by the equation $\boldsymbol{r}(t) = A(\boldsymbol{i}\cdot\cos\omega t + \boldsymbol{j}\cdot\sin\omega t)$, where $A = 0{,}5m; \omega = 5 rad/s$. Represent the trajectory of the material point in the figure and determine its speed υ and the normal acceleration modulus a_n

2. The time dependence of the disk angle rotation around a fixed axis is given by the equation $\varphi = A + Bt + Ct^2 + Dt^3$, where $B = 1 rad/s; C = 1 rad/s^2; D = 1 rad/s^3$. For the points situated at the distance $r = 8sm$ from the rotation axis at the end of the third second after the start of motion: determine: 1) tangential acceleration a_τ; 2) normal acceleration a_n; 3) total acceleration a_{tot}.

3. A body with mass $m - 2kg$ moves rectilinearly according to the law $x(t) = A + Bt + Ct^2 + Dt^3$, where $C = 2 m/s^2$; $D = 0{,}4 m/s^3$. Determine the force F_x that acts on the body at the end of the first second from the start of the motion.

4. The electric locomotive pushes two cars of a masses $m_1 = m_2 = 60t$ giving them acceleration $a = 0{,}1 m/s^2$. Determine: 1) force F_1 compressed the buffers between the cars; 2) force F_2 compressed the buffers between the electric locomotive and the car. The resistance coefficient is considered to be $\mu = 0{,}005$.

5. Along an inclined plane situated. under the angle $\alpha = 30°$ to horizont a solid homogeneous cylinder moves. Mass of the cylinder is $m = 5kg$, its radius $r = 0{,}1m$. When the cylinder moves the sliding is assumed to be absent. Determine a linear acceleration of the cylinder center of inertia.

6. The flywheel rotates according to the law $\varphi = A + Bt + Ct^2$, where $A = 2rad, B = 32 rad/s; C = -4 rad/s^2$. Determine the average power $\langle N \rangle_{\Delta t}$ developing by the forces acting on the flywheel during its rotation time Δt until its stop if the moment of inertia of flywheel relative the rotation axis is $J = 100 kg\cdot m^2$.

7. Determine the relativistic particle momentum p (in units mc) if its kinetic energy T is equal to the rest one E_0.

5. DRAWING UP A REPORT ON THE PERFORMED LABORATORY WORK

1. The name of the work and its number.
2. The purpose of the work.
3. The devices and materials using in the work.
4. Brief theoretical knowledges.
5. Description of the experimental device and its figure.
6. Description of the work order.
7. Table of the data obtained as a result of the experiment.
8. Representation of the work results in the form of a plot if it is required by the instruction.
9. Data processing (an example of the error calculation)
10. The final result of the work in the form

$$x = \langle x \rangle \pm \Delta x = \ldots, \text{ when } \alpha = \ldots$$

CONTENTS