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Department of Physics

PHYSICS 1

Lecture synopsis for students of specialty
5B070200 – Automation and control

Almaty 2016

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We present a synopsis of lectures on the discipline "Physics 1" for students specialty 5B070200 - Automation and control.

Lectures "Physics 1" are another element of the system of methodological maintenance of educational process on the discipline and can be used as a handout to the lectures, as well as in the CGW of the theoretical material while preparing for practical, laboratory work and exams.

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Introduction

Studying the physics course creates a fundamental base of engineering - technical knowledge and skills of graduates of higher technical school, forms of scientific outlook.

The main objectives of the course are:

- formation of students' skills in using fundamental laws of classical physics theories and methods of physical research as the basis of their professional activity;
- formation of students' creative thinking and scientific outlook, skills of independent cognitive activity, the ability to modulate physical situations.

The course "Physics 1" study such areas as: mechanics, statistical physics and thermodynamics, an electrostatics and direct current, magnetism.

Acquired in the study of physics knowledge and skills constitute the foundation that is needed in the study of technical disciplines.

1 Lecture №1. Introduction. Dynamics of a solid body

Lecture content: movement equation of a solid body and basic dynamics concepts of rotary motion are briefly given in the lecture.

Lecture objectives: to study dynamics of a solid body, i.e. to understand the meaning of main tasks of mechanics and methods of their solution.

1.1 Mechanical motion. Space and time. Frame of reference

The subject of mechanics is studying mechanical motion of bodies and interactions between them connecting with their movement. *Change of mutual position of bodies or their parts in space over time is called a mechanical motion.*

Concepts of *space and time* are the base for creating a physical theory. The space and time do not exist separately from substance; they are forms of matter existence integrally connected among each other. The space expresses the order of material objects coexistence, time is the order of natural phenomena change.

Abstract mathematical models of space and time (for example, Euclidean's space) illustrate properties of real space and time as main objectives in studying physics.

Any movement is relative. To describe mechanical movement it is necessary to choose a frame of reference: set of a body reference, a system of coordinates and hours.

1.2 Main objective of mechanics. Movement equation of a solid body

The main objective of mechanics is to define of the state of a studied system (material point, totality of material points, solid body) at any moment of time if the condition of this system at the initial moment is known. In classical mechanics the state of a particle is completely characterized if three of its coordinates (x, y, z) and three projections of impulse (p_x, p_y, p_z) at a given point of time are known.

A solid body can perform various complex movements (examples from technique). All of them can be considered as addition of two simple movements: *translational and rotary*. Translational motion of a solid or rigid body is equivalent to the movement of a particle with mass equal to the mass of the body and placed in its *center of inertia*. At a rotary motion movement all points of a body move round a fixed axis in circles with the centers lying on this axis. In this case the state of a body can be set by rotation angle round the axis and angular speed as well as angular acceleration.

1.3 Basic concepts of dynamics of rotary movement: angular momentum, moment of force (torque), moment of inertia

Angular momentum of a particle concerning a point "O" is equal to the vector \vec{L}_0 as:

$$\vec{L}_0 = [\vec{r} \cdot \vec{p}], \quad (1.1)$$

where \vec{r} – radius - vector of the particle at the present point of time;
 \vec{p} – its momentum ($\vec{p} = m\vec{v}$).

The vector of an angular momentum is perpendicular to the plane in which vectors \vec{r} and \vec{p} lie (figure 1.1).

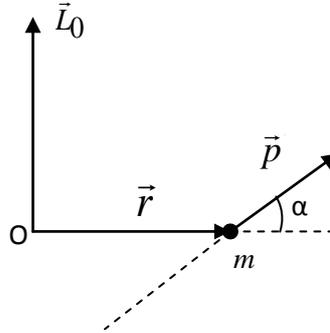


Figure 1.1

The angular momentum of a system of particles is equal to the vector sum of angular momentums of all particles of the system

$$\vec{L} = \sum \vec{L}_{0i} \quad (\text{similarly: } \vec{p} = \sum \vec{p}_i). \quad (1.2)$$

Vector \vec{M}_0 is called *the force momentum (or torque) concerning point O* and equal to:

$$\vec{M}_0 = [\vec{r} \cdot \vec{F}], \quad (1.3)$$

where \vec{r} – radius-vector of a point of force application \vec{F} .

Momentum of force characterizes a force ability to cause rotation of a body round a given point. A body fixed in point O will turn round the axis coinciding with the direction of torque \vec{M} under the influence of force \vec{F} (Figure 1.2).

Time derivative from (1.1) shows that the velocity of change of the angular momentum for a particle is defined by momentum of force

$$\frac{d\vec{L}}{dt} = \vec{M}. \quad (1.4)$$

Ratio (1.4) is the equation of force moments.

Let's consider that a rigid body can rotate round fixed axis Oz and force \vec{F} is applied to the body. Projection M_z of force momentum \vec{M}_0 concerning point O is

called a *force momentum (torque)* \vec{F} concerning an axis of Oz . It characterizes the ability of this force to cause rotation round this axis and is equal to

$$M_z = ([\vec{r} \cdot \vec{F}])_z = RF_{\perp} \sin \alpha = F_{\perp}l, \quad (1.5)$$

where l – shoulder of force F_{\perp} , equal to $R \sin \alpha$;

\vec{r} – radius-vector;

F_{\perp} – force projection \vec{F} on this plane.

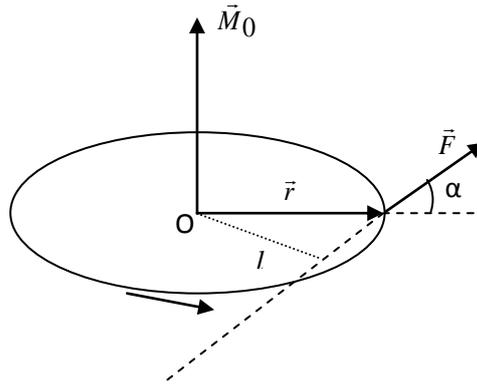


Figure 1.2

Angular momentum of a body concerning an axis can be defined if we will take a projection to this axis of total angular momentum concerning point O of all particles of this body (figure 1.3)

$$L_z = (\sum \vec{L}_{0i})_z = (\sum [m_i \cdot \vec{r}_i \cdot \vec{v}_i])_z. \quad (1.6)$$

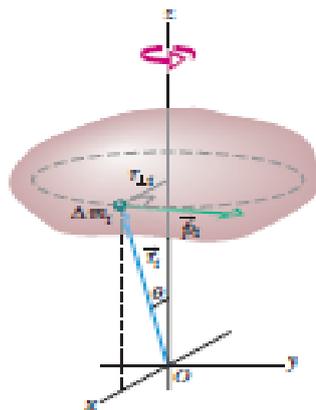


Figure 1.3

It is easy to be convinced that expression (1.6) can be transformed and expressed:

$$L_z = \sum \omega \cdot m_i \cdot R_i^2 = \omega \cdot \sum m_i \cdot R_i^2. \quad (1.7)$$

Value

$$J_z = \sum m_i \cdot R_i^2 \quad (1.8)$$

is called *the moment of inertia* of a body concerning an axis. The moment of inertia depends on distribution of body mass round an axis and characterizes inert properties of the body at a rotary movement. Thus, we have

$$L_z = J_z \cdot \omega, \text{ or } \vec{L} = J \cdot \vec{\omega}. \quad (1.9)$$

From (1.4), (1.5) in regard to (1.9) we will receive

$$M_z = J_z \cdot \varepsilon, \quad (1.10)$$

where M_z – torque of all forces concerning axis Z;

J_z – moment of inertia of a body concerning this axis;

ε – angular acceleration of the rotating body.

Expression (1.10) represents the fundamental law of dynamics of rotary movement of a solid body round motionless axis.

2 Lecture № 2. Mechanical energy, work and power

Lecture content: the concepts of energy, work and power and as well as methods of calculation of different types of energy are briefly given in the lecture.

Lecture objective: to study mechanical energy, work and power.

2.1 Energy as general measure of various forms of matter movement in mechanics

There are many forms of movement of a matter. Mechanical movement is the simplest of them. For its quantitative description we the concept of an impulse (momentum) $\vec{p} = m\vec{v}$ in the previous lecture. The quantitative characteristic in the case of thermal movement is temperature T , of an electric field is \vec{E} etc. All these values illustrate qualitative features of various forms of movement of a matter. But various forms of movement have mutual convertibility. Therefore, it is necessary to introduce such physical quantity which refers to all forms of matter movement and proves their mutual convertibility. Such physical value is energy. It is one of the most general concepts in physics.

Energy is a uniform measure of various forms of matter movement. (It is necessary to notice: the concept of energy "is not discovered", but it is introduced into physics. It is a product of cogitative activity of human).

As movement is an integral property of matter, any system possesses energy. Energy of a system characterizes quantitatively this system from the point of view of possible changes in it (quantitative and qualitative). *Energy is function of a state.*

There are processes in the nature where mechanical movement and energy are continuously transferred from one body to another. The change of mechanical movement of a body is caused by forces acting to it from other bodies. The process of energy exchange between interacting bodies is characterized quantitatively by work of force applied to the body. *Work is a measure of energy change in processes of force interaction.*

2.2 Kinetic energy and work of force

Let's consider a particle with mass m and force \vec{F} acting to it. The equation of Newton's second law for this particle is expressed:

$$m \frac{d\vec{v}}{dt} = \vec{F} . \quad (2.1)$$

Let's multiply equation (2.1) by vector $d\vec{r}$ of infinitesimal displacement of the particle (let's consider that $d\vec{r} = \vec{v} dt$)

$$m \left(\vec{v} \frac{d\vec{v}}{dt} \right) dt = (\vec{F} d\vec{r}) . \quad (2.2)$$

As seen in figure 2.1 scalar product $\vec{v} d\vec{v}$ equals:

$$\vec{v} d\vec{v} = v dv \cos \alpha = v |d\vec{v}|_{\tau} = v dv = d \left(\frac{v^2}{2} \right) .$$

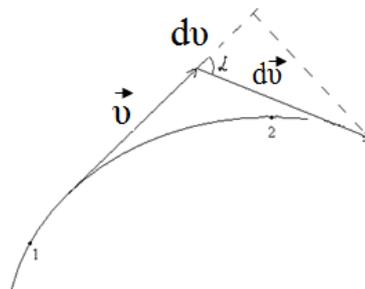


Figure 2.1

Therefore,

$$m \left(\frac{v^2}{2} \right) = \vec{F} d\vec{r} . \quad (2.3)$$

The value in the right part of equation (2.3) is called work dA of force \vec{F}

$$dA = (\vec{F}d\vec{r}) = Fdr \cos \alpha , \quad (2.4)$$

where α is the angle between force \vec{F} and displacement $d\vec{r}$.

Formula (2.4) expresses elementary work of force \vec{F} . At the body displacement on final distance the full work is expressed by curvilinear integral along movement trajectory

$$A_{12} = \int_1^2 dA = \int_l (\vec{F}d\vec{r}) = \int_l F_l dl . \quad (2.5)$$

Work of force is an algebraic value, it can be positive, negative and is equal to zero. The graphical representation of work is shown in figure 2.2.

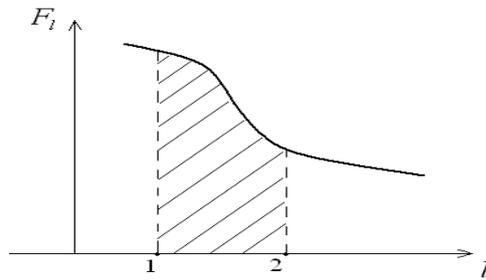


Figure 2.2

Let's consider the left part of equation (2.3). It represents a full differential of a function

$$W_k = \frac{mv^2}{2} + const . \quad (2.6)$$

Value W_k is called kinetic energy of a particle. *Kinetic energy is a part of total energy of a particle connected with its movement.* A body at rest ($v=0$) does not have kinetic energy that's why (2.6) is expressed:

$$W_k = \frac{mv^2}{2} = \frac{p^2}{2m} . \quad (2.7)$$

Kinetic energy of a solid body at rotary movement round a motionless axis is equal to

$$W_k = \frac{J\omega^2}{2} = \frac{L^2}{2J} . \quad (2.8)$$

Expressions (2.7) and (2.8) are valid only for the non-relativistic particles ($v \ll c$). Equation (2.7) is valid and in the case when a particle is affected by some forces. Then A_{12} is the sum of works of all forces. Thus, the *change of kinetic energy of a particle is equal to work of all forces acting on this particle*

$$A_{12} = W_{k2} - W_{k1}. \quad (2.9)$$

The physical value equal to the work referred to a unit of time is called the power

$$N = \frac{dA}{dt}. \quad (2.10)$$

2.3 Conservative and non-conservative forces. Potential field of forces

All forces, irrespective of their physical nature, are divided into two classes: conservative and non-conservative. Force is called conservative if its work does not depend on particle trajectory, i.e. from initial to final points of movement

$$A_{12} = \int_{l_1} (\vec{F} d\vec{r}) = \int_{l_2} (\vec{F} d\vec{r}). \quad (2.11)$$

The work of conservative force is equal to zero if moving on a closed path

$$\oint \vec{F} d\vec{r} = 0. \quad (2.12)$$

Central forces (gravitational and coulomb) as well as gravity and elastic forces are conservative.

Work of non-conservative force depends on the path on which it moves. An example of such forces is the friction force, medium resistance force. Work of friction force is always negative. Such forces are called dissipative.

Field of forces is called a space area where a particle is affected by a force regularly changing forces from point to point $\vec{F}(\vec{r})$. Force fields are vector ones. A force field can be uniform (a gravity field) and central (gravitational field). Fields of conservative forces have a number of characteristic properties, they form a class of *potential fields*. Such a field in each point can be characterized by some function $W_p(\vec{r})$ depending on position of a point in space and character of force $\vec{F}(\vec{r})$. In this case the work of conservative force $\vec{F}(\vec{r})$ when a particle moves between points 1 and 2 is equal to a decrease of function W_p

$$A_{12} = W_{p1} - W_{p2} = -\Delta W_p. \quad (2.13)$$

Function W_p is called potential energy of a particle in an external conservative field. From expression (2.13) follows that work in such a field is made due to potential energy.

Potential energy of a particle $W_p(\vec{r})$ always has the meaning of interaction energy with the objects creating a field. Formula (2.13) allows to receive expressions for W_p in each case (accurate to any constant).

We can receive relations between force and energy of particle being in a potential field. For this purpose we will write down elementary work

$$dA = -dW_p = (\vec{F}d\vec{r}) = F|d\vec{r}|\cos\alpha = F_l dl. \quad (2.14)$$

Force projection \vec{F} on any direction l is expressed:

$$F_l = -\frac{\partial W_p}{\partial l}. \quad (2.15)$$

If we take the direction of movement along axes of coordinates x, y, z we receive

$$\vec{F} = -\left(\frac{\partial W_p}{\partial x} \vec{i} + \frac{\partial W_p}{\partial y} \vec{j} + \frac{\partial W_p}{\partial z} \vec{k} \right) \quad (2.16)$$

or $\vec{F} = -gradW_p$.

Formula (2.16) expresses the connection between energy and force in a potential field.

3 Lecture №3. Conservation laws and principle of relativity in mechanics

Lecture content: base of conservation laws and methods of using these laws in practice, principle of relativity in mechanics are briefly given in this lecture.

Lecture objectives: to study conservation laws, to understand main meaning of these laws as fundamental laws of nature, to understand principles of a special theory of relativity.

3.1 Conservation laws of momentum and angular momentum

Conservation law of momentum is a general law of nature in the base of which there is *uniformity of space*, i.e. similarity of properties of space in all its points.

This law is observed only for isolated systems. Really, if a system is placed in an external field of forces different areas of space will not be equivalent for it any more.

A system of interacting objects not affected by external forces is called isolated or closed.

Full momentum of a closed system of material points (bodies) does not change eventually

$$\frac{d\vec{p}}{dt} = 0, \quad \vec{p} = \sum_{i=1}^N \vec{p}_i = \text{const}. \quad (3.1)$$

While concluding the fundamental law of dynamics of rotary movement we considered a solid body as a system of material points and came to a ratio

$$\frac{d\vec{L}}{dt} = \vec{M}, \quad (3.2)$$

where $\vec{L} = \sum \vec{L}_i$ – angular momentum of the system;

\vec{M} – total momentum of external forces acting the system.

The sum of moments of internal forces for any system is always equal to zero.

If external forces are absent (a system is closed) $\frac{d\vec{L}}{dt} = 0$, therefore $\vec{L} = \text{const}$.

The angular momentum of a closed system of material points (bodies) remains constant

$$\vec{L} = \sum \vec{L}_i = \text{const}. \quad (3.3)$$

If a body rotates round a motionless axis and $M_z = 0$, $L_z = \text{const}$; considering that $L_z = J\omega$, we receive

$$\sum_{i=1}^N L_z = J_i \omega_i = \text{const}. \quad (3.4)$$

Angular momentum conservation law like the law of conservation of momentum is the fundamental law of nature. *The property of space isotropy is in its base*, i.e. the turn of the a closed system as a whole does not influence on its mechanical properties.

3.2 The law of energy conservation in mechanics

The law of energy conservation and transformation is one of fundamental laws of nature. *Uniformity of time*, i.e. equivalence of all time-points is the cornerstone of energy conservation. Different time-points are equivalent in that any physical process proceeds equally irrespective of when it began. The law of energy conservation and transformation has a deep physical meaning. It confirms that the

movement is an integral property of matter, it is uncreatable and indestructible, and it is only transformed from one forms into others.

Let's consider total mechanical energy of a particle and a system of particles.

Let's return to formula (2.9). Let a particle be affected by conservative forces \vec{F}^* and non-conservative \vec{F} . So,

$$W_{k1} - W_{k2} = A_{12}^* + A_{12}.$$

As $A_{12}^* = W_{p1} - W_{p2}$, we will receive

$$(W_{k2} + W_{p2}) - (W_{k1} + W_{p1}) = A_{12}. \quad (3.5)$$

Total mechanical energy W of a particle is the sum of its kinetic and potential energy. The change of total mechanical energy of the particle being in the field of conservative forces is equal to work of non-conservative forces affecting the particle

$$W_2 - W_1 = A_{12}. \quad (3.6)$$

Energy of system N of non-interacting particles is defined as the sum of all energy of particles making this system

$$W = \sum_{i=1}^N W_i = \sum_{i=1}^N (W_{ki} + W_{pi}). \quad (3.7)$$

If particles interact between themselves, it is necessary to consider energy of their interaction which is not an additive value any more

$$W = \sum_{i=1}^N (W_{ki} + W_{pi}) + W_{\text{int}}. \quad (3.8)$$

In system, where only conservative forces operate between particles (such system is called conservative) but external forces are absent ($A_{12} = 0$), its total mechanical energy remains constant as it follows from a formula (3.6). And this statement is the law of conservation of mechanical energy. It is obvious that *total mechanical energy remains constant only for a closed conservative system of bodies.*

The laws of conservation of momentum, angular momentum and energy became a very powerful and effective instrument of research. This important role of conservation laws is caused by a number of reasons:

- conservation laws do not depend on neither trajectories of particles, nor on character of acting forces. Therefore they allow to receive a number of very general

and essential conclusions about properties of various mechanical processes, without detailed consideration by means of movement equations;

- this fact allows to use the conservation laws even when forces are unknown in general (collisions of bodies, molecules).

3.3 Einstein's postulates. Special theory of relativity

The Special Theory of Relativity (STR) is a physical theory of space and time in which it is supposed that space is uniform and isotropic and time is uniform.

Two postulates are the cornerstone of Einstein's special theory of relativity generalized principle of relativity and principle of constancy of light speed in vacuum:

- all physical phenomena in inertial frames reference proceed equally;
 - light speed in vacuum is identical in all inertial frames reference and does not depend on movement of sources and receivers of light, i.e. it is a universal constant. It is equal to

$$c = 2,99793 \cdot 10^8 \text{ m/s.}$$

Consequences from Einstein's main postulates are:

- time passes differently in different inertial frames reference. The statement that certain period passed between two given events has its meaning only when it is specified, to what frame reference this statement refers; simultaneous events in a certain frame reference, can be non-simultaneous in another system;

- relativity of time intervals of the same event in frames reference K and K' is:

$$\Delta t' = \Delta t \sqrt{1 - \frac{v^2}{c^2}}. \quad (3.9)$$

The time counted down in hours moving together with an object is called the own time of this object. Let's designate it τ_0 , so

$$\Delta t = \frac{\Delta \tau_0}{\sqrt{1 - \frac{v^2}{c^2}}}. \quad (3.10)$$

Moving hours go slower than motionless ones. Slowing down of time in the system where hours are in rest is not seeming and not connected with influence of hours movement on their work, but it shows a relative character of time. So, there is no uniform world time. Time, its current and concepts of simultaneity of events are relative.

Relativity of spatial intervals

$$\Delta l = \Delta l_0 \sqrt{1 - \frac{v^2}{c^2}}. \quad (3.11)$$

Rod length Δl_0 , measured in a frame reference in which the rod is not mobile, is called *own length*. As seen in (3.11), this length is maximum, i.e. in all frames reference the length of bodies decreases in comparison with the own one. This phenomenon is called *Lorentz's reduction of bodies sizes in the direction of movement*. Lorentz's reduction of geometrical sizes of bodies is not seeming and not connected with physical influence of movement on body sizes. It reflects not absoluteness of spatial intervals but their dependence on a choice of frame reference.

3.4 Lorentz's transformations and invariants of the theory of relativity

The relativistic transformations of coordinates and time showing properties of space and time in the special theory of relativity are called Lorentz's transformations. According to these transformations, transition from system K' to system K is carried out according to formulas (3.12), and from system K to system K' according to formulas (3.13)

$$x = \frac{x' + vt'}{\sqrt{1 - \frac{v^2}{c^2}}}, \quad y = y', \quad z = z', \quad t = \frac{t' + \frac{x'v}{c^2}}{\sqrt{1 - \frac{v^2}{c^2}}}, \quad (3.12)$$

$$x' = \frac{x - vt}{\sqrt{1 - \frac{v^2}{c^2}}}, \quad y' = y, \quad z' = z, \quad t' = \frac{t - \frac{xv}{c^2}}{\sqrt{1 - \frac{v^2}{c^2}}}. \quad (3.13)$$

On the basis of received transformations of coordinates and time it is possible to give one more formulation of the principle of relativity: *physical laws are invariant regarding Lorentz's transformations*.

4 Lecture №4. Statistic distributions

Lecture content: the main meaning of statistic and thermodynamic methods of research are briefly given in this lecture.

Lecture objective: to study fundamental laws of classical static physics.

4.1 Statistic and thermodynamic methods of research

Statistic physics and thermodynamics are two interrelated parts of physics studying the most general properties of macroscopic physical systems including also the systems directly connected with our life support.

The main *objective of thermodynamics* is studying properties of material bodies. They are characterized by values measured directly in experiments

(macroscopic parameters: volume, temperature, pressure, etc.) on the base of absolutely right general principles of *thermodynamics*. There are three laws of *thermodynamics*. Thus model ideas of a substance structure are not attracted. Thermodynamics conclusions are right in the same degree as the laws of thermodynamics.

Statistic physics is based on *model atomic-molecular ideas* about macro bodies structure (for example, ideal gas model) and mathematical statistics. Properties of macro systems are eventually defined by properties of system particles, features of their movement and average values of dynamic characteristics of these particles (energy, speed, etc.). Statistic physics gives calculation ways of similar averages and with their help determines macro parameters of systems. The main equation of the molecular - kinetic theory was so received

$$p = \frac{2}{3} n \langle \varepsilon_n \rangle , \quad (4.1)$$

where p – gas pressure;

n – number of gas molecules in a unit of volume (concentration of molecules);

$\langle \varepsilon_n \rangle$ – average energy of translational movement of molecules.

Both methods – thermodynamic and statistic have their own advantages and disadvantages. Their coordinated application gives the fullest and reliable result.

4.2 The law of uniform distribution of energy according to degrees of freedom

Basic concepts are number of freedom degrees of molecule i , translational, rotary and oscillatory degrees of freedom.

One of the most important laws of static physics applicable to classical systems is *the law of uniform distribution of energy according to degrees of freedom*: in condition of thermal balance a molecule has the identical kinetic energy equal on average on each freedom degree $\frac{1}{2} kT$. Here $k = 1,38 \cdot 10^{-23} \frac{J}{K}$ – Boltzmann's constant.

At chaotic movement none types of molecule movement has advantages over another one, but it should be borne in mind that oscillating motion is connected with transition of kinetic energy into potential and vice versa. In accounting atoms fluctuations energy in a molecule it is necessary to take into account average kinetic and average potential energy. Total energy of a molecule is:

$$\langle \varepsilon \rangle = \frac{i}{2} kT , \quad (4.2)$$

$$i = i_{trans} + i_{rot} + 2i_{osc} , \quad (4.3)$$

where i – number of freedom degrees of a molecule.

4.3 Maxwell's law for molecules distribution on velocities

Let's consider a gas in a condition of thermodynamic balance. The movement of its particles submits the laws of classical mechanics. Let the gas contain N molecules, the mass of each molecule is m . Thermal chaotic movement is characterized by uniform distribution of molecules in all direction of movement (all directions are equally probable). But numerical values of molecules velocities cannot be identical. Then some distribution on molecules velocities has to be established due to collisions which will not depend on time.

Let the velocity of a gas molecule accept values $0 \leq v \leq \infty$. In this case we have a question: how many molecules dN from total number N have the velocities in some interval dv near a given velocity v ?

It is obviously

$$dN = Nf(v)dv . \quad (4.4)$$

Function

$$f(v) = \frac{dN}{Nd v} \quad (4.5)$$

is called *the distribution function of molecules on velocities*. It has the following meaning: $f(v)$ defines a part of molecules which velocities are in a single interval near a given value v . Function $f(v)$ satisfies the condition of normalization

$$\int_0^{\infty} f(v)dv = 1.$$

The problem about distribution of gas molecules velocities was formulated and solved by J. K. Maxwell in 1859 - 1860. Maxwell's distribution function is shown in figure 4.1 and is expressed by a formula:

$$f(v) = 4\pi v^2 \left(\frac{m}{2\pi kT} \right)^{\frac{3}{2}} e^{-\frac{mv^2}{2kT}} . \quad (4.6)$$

The probability of velocity value for a randomly chosen molecule lies in interval $(v, v + dv)$ and is equal to $dP(v, v + dv) = \frac{dN}{N} = f(v)dv$.

Main properties of Maxwell's distribution are:

- only a small percent of molecules has very small and very big velocities;

- there is a value of velocity v_{mp} (the most probable velocity) corresponding to a function maximum $f(v)$ so, a considerable part of molecules has velocities close to v_{mp} . It is easy to show that

$$v_{mp} = \sqrt{\frac{2kT}{m}} = \sqrt{\frac{2RT}{\mu}} ; \quad (4.7)$$

- a part of molecules with velocities exceeding v_{mp} is always more, than a part of molecules with velocities $v < v_{mp}$. This disproportion increases with rise of temperature (curves for T_1 and T_2 in function graph $f(v)$ $T_2 > T_1$).

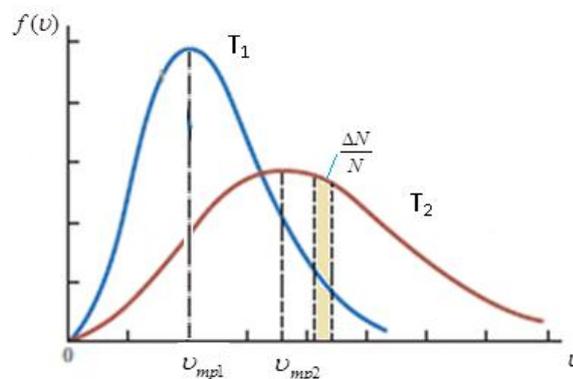


Figure 4.1

If we know distribution function, it is possible to find an average value of any physical quantity depending on velocity. Arithmetic average velocity is equal to

$$\langle v \rangle = \int_0^{\infty} v f(v) dv = \sqrt{\frac{8RT}{\pi\mu}} .$$

Thus,

$$\langle v \rangle = \sqrt{\frac{8RT}{\pi\mu}} . \quad (4.8)$$

Root mean square velocity $\langle v^2 \rangle = \sqrt{\langle v^2 \rangle}$,

$$\langle v^2 \rangle = \int_0^{\infty} v^2 f(v) dv = \frac{3kT}{m} .$$

Thus,

$$v_{rms} = \sqrt{\frac{3kT}{m}} . \quad (4.9)$$

Type of distribution $f(v)$ doesn't depend on interaction of particles. It is defined only by the ability of particles to exchange energy in the process of setting an equilibrium state. The temperature in Maxwell's law is the parameter which determines the form of curve. It is possible to speak about temperature of system only in the case when thermal (chaotic) movement of particles was established in the system and their velocities are distributed according to Maxwell's law.

4.4 Boltzmann's law for distribution of particles in an external potential field

At a thermal movement all directions of particle movement are equally probable and the change in the position of each particle has a casual character. Therefore it is possible to speak about the probability of detection of a particle in this or that place.

Let an ideal gas occupy volume V and it is in an equilibrium state with temperature T . In the absence of an external field all positions of any molecule are equally probable. Therefore the gas is distributed in all volume with identical concentration $n = \frac{N}{V}$.

If a gas is in an external force field the particles of the gas undergo the action of this field and the picture changes. Density and pressure of the gas prove to be different in various places. Let's consider the case when forces of an external field are potential and act only in one direction h , where h is a height above the earth's surface. Let's designate potential energy of a particle $\varepsilon(h)$. It is possible to show that the concentration of gas particles undergone by the action of an external field is measured in a condition of thermal balance according to the law:

$$n(h) = n_0 e^{-\frac{\varepsilon(h)}{kT}} = n_0 e^{-\frac{mgh}{kT}} = n_0 e^{-\frac{\mu gh}{RT}}. \quad (4.10)$$

This ratio is called Boltzmann's law.

Let's consider the field of Earth's gravity. Near the Earth's surface potential energy of a molecule is equal to $\varepsilon(h) = mgh$ (Figure 4.2). Taking into account that $p = nkT$, we will receive gas pressure at height h above the earth's surface

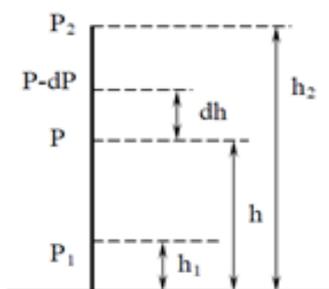


Figure 4.2

$$p(h) = p_0 e^{-\frac{mgh}{kT}} = p_0 e^{-\frac{\mu gh}{RT}}. \quad (4.11)$$

This formula is called barometric. It can be applied also for rather discharged mixture of gases (air). Both these distributions can be combined into one Maxwell-

Boltzmann's law. It is applicable for real gases if we can neglect the interaction of molecules at a distance. There is a derogation from this law at low temperatures because in this case a gas doesn't obey classical distributions.

5 Lecture №5. Fundamentals of thermodynamics. Thermodynamics second beginning

Lecture content: the basic concepts of thermodynamics are briefly given in this lecture.

Lecture objectives: to study fundamental laws of thermodynamics and methods of analysis of the macro system processes.

5.1 Warmth and work as forms of energy exchange in thermodynamics. Thermodynamics first beginning

Internal energy U of macroscopic bodies differs qualitatively from mechanical energy of system of particles. This difference appears in existence only of two forms of internal energy change – *works and warmth*.

Work A is a measure of change of internal energy of a system in force interactions with the environment. Work implementation is always connected with emergence of ordered movement, as well as change of external parameters of the system (for example, the volume V).

Warmth Q is a measure of internal energy of a system in heat transfer processes and it is not followed by change of external parameters. Heat transfer mechanisms are heat conductivity, radiation and convection.

Warmth and work are not types of energy, but forms of energy exchange.

The energy conservation law shows that are possible in thermodynamics only two ways of energy exchange between a system and the medium. It is the fundamental law of physics: *the internal energy of a system is changed due to the warmth transferred to the system and as well as the work made over the system. This law is called also a thermodynamic first beginning.*

$$dU = \delta Q + \delta A'$$

or

$$\delta Q = dU + \delta A \quad (5.1)$$

$$\text{here } \delta A = pdV, \quad dU = \frac{m}{\mu} C_v dT, \quad \delta Q = \frac{m}{\mu} C_p dT,$$

where A' - the work is made over system;

A - work of the system made over external forces.

Internal energy is a function of a system state. Its change depends only on initial and final states and does not depend on a way of transition between states (figure 5.1).

Warmth and work depend not only on these states, but also on a type of process; they are functions of the process.

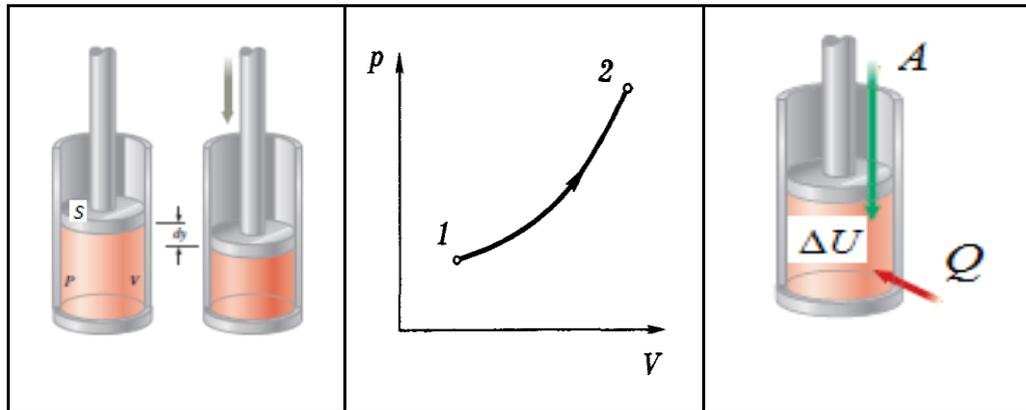


Figure 5.1

5.2 Thermodynamics second beginning

5.2.1 Circular processes. Efficiency of heat engines.

Thermodynamics first beginning shows a possibility to make work due to heat received by a system from external bodies. The operation of a thermal machine is based on transformation of heat Q_1 received from a heater at temperature T_1 into work A .

However, the operation of thermal machines is based on circular (cyclic) processes in which the system (a working body) reverts to the initial state after a number of changes. In this case warmth quantity Q_2 will be given to the environment at temperature T_2 .

The work of a thermal machine can be described as following: a working body receives warmth Q_1 from a heater then gives to refrigerator Q_2 and it transforms difference of these warmth into useful work $A = Q_1 - |Q_2|$ (figure 5.2).

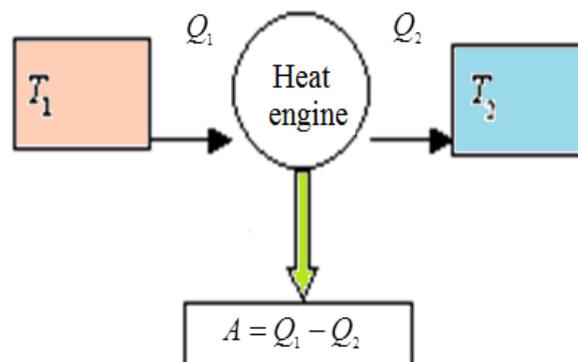


Figure 5.2

Warmth Q_2 is kind of "tax" which one has to pay to the nature for the possibility of transformation of a warmth quantity into useful work. The potency of a heat engine is characterized by its efficiency

$$\eta = \frac{A}{Q_1} = \frac{Q_1 - Q_2}{Q_1} < 1 . \quad (5.2)$$

Expression (5.2) shows that the efficiency of thermal engine is principally less than one unit. This result is not a consequence of thermodynamics first beginning but it expresses the content of the other fundamental law – *thermodynamics second beginning*. Other formulations of this law are:

- a cyclic process the only as a result of which is work production and energy exchange with one thermal reservoir is impossible (W. Thomson);
- a perpetual motion machine of the second type is impossible (V. Oswald);
- a cyclic process the only result of which warmth would be transfer from a body heated less to a body heated more is impossible (R. Clausius).

Empirical formulations of the second beginning are not expressed in a mathematical form. Being externally various they have an internal unity. In essence they are equivalent to each other.

5.2.2 Carnot's cycle. Carnot's and Clausius's theorems.

Carnot's cycle has a special place among all cyclic processes. Studying the cycle is connected with the discovery of thermodynamics second beginning. This is *the only cycle that can be performed reversibly* in the presence of one heater (T_1) and one refrigerator (T_2). Carnot's cycle consists of two isotherms and two adiabats. If a working body is an ideal gas we will receive the efficiency for Carnot's reversible cycle by means of ratios (figure 5.3).

$$\eta_0 = \frac{Q_1 - |Q_2|}{Q_1} = \frac{T_1 - T_2}{T_1}, \quad \eta_0 = \frac{T_1 - T_2}{T_1}. \quad (5.3)$$

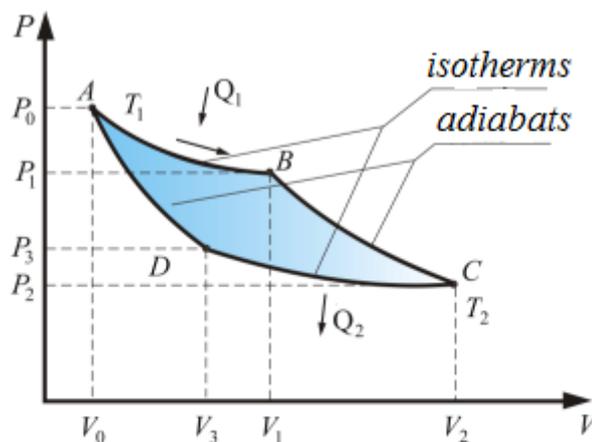


Figure 5.3

Carnot's theorem is:

- The efficiency of Carnot's reversible cycle does not depend on the nature of a working body and as well as system structure carrying out this cycle but it is defined only by heater temperature T_1 and refrigerator T_2 ;
- The efficiency of irreversible engines (working on irreversible cycle) is less than efficiency of reversible engines, i.e. $\eta < \eta_0$. Therefore,

$$\frac{Q_1 - Q_2}{Q_1} \leq \frac{T_1 - T_2}{T_1}. \quad (5.4)$$

Strictly reversible processes in macro systems are impossible, therefore expression (5.3) has an asymptotic character. It is possible to approach to it, but one cannot reach an exact value.

Carnot's theorem (5.4) is a mathematical expression of thermodynamics second law applied to closed processes with one heater and one refrigerator. An equal sign in (5.4) takes place for reversible processes, and an inequality sign – for irreversible ones.

Clausius's inequality (Clausius's theorem) is the synthesis of Carnot's theorem for the case of random cycles

$$\oint \frac{\delta Q}{T} \leq 0. \quad (5.5)$$

5.2.3 Entropy. Thermodynamics second law as the law of entropy increasing.

All considered formulations of thermodynamics second law show that energy account and conservation are not sufficient to evaluate the possibility of occurring this or that process. Energy has to be characterized not only quantitatively, but also qualitatively. The value defining quality of energy and allowing to describe quantitatively restrictions of thermodynamics second law is entropy S .

Let's write down Clausius's theorem (5.5) for a random reversible cycle

$$\oint \frac{\delta Q}{T} = 0. \quad (5.6)$$

From ratio (5.6) follows that value $\frac{\delta Q}{T}$ represents a full differential of a *state function* S and is expressed: $dS = \frac{\delta Q}{T}$ and therefore,

$$S_2 - S_1 = \int_1^2 \frac{\delta Q}{T}. \quad (5.7)$$

Formulas (5.7) should be considered as certain concepts of entropy in thermodynamics. Some properties of entropy follow from its definition (5.7):

- entropy of a system is an additive value $S = \sum S_i$;
 - at reversible process without heat exchange ($\delta Q = 0$), i.e. at the adiabatic process, the entropy remains constant;
 - entropy of a process can be defined only accurate to random constant value.
- Changing entropy in reversible processes is calculated on the basis of ratios (5.7) and (5.1)

$$TdS = dU + \delta A. \quad (5.8)$$

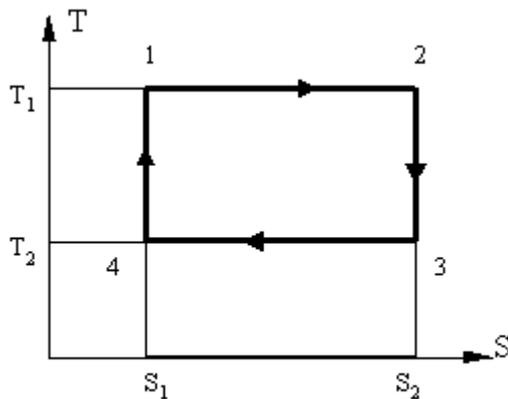


Figure 5.4

For analysis of thermal processes TS diagrams are used where state functions T and S are chosen as axes of coordinates (figure 5.4). A deep physical meaning of entropy is revealed in static physics. L. Boltzmann showed that entropy S is defined by a logarithm of number of microstates P by means of which the considered macro state is realized

$$S = k \ln P, \quad (5.9)$$

where k – Boltzmann's constant;

P – static weight of a given macro state.

Formula (5.9) is called Boltzmann's formula. It allows to give to entropy an evident interpretation.

Let's suppose that all atoms are rigidly fixed in certain places. Then there is only one microstate, $P=1$ and $S=0$. Transferring of a quantity of warmth to the system increases disorder of internal structure and randomness of movement of particles forming it (P grows). Therefore one can say that entropy is a measure of disorder.

The most general formulation of thermodynamics second law is connected with the concept of entropy: *entropy does not decrease in an isolated system*

$$\Delta S \geq 0, \quad S_2 \geq S_1. \quad (5.10)$$

An equality sign in expression (5.10) corresponds to the case when there are only reversible processes in a system and entropy remains invariable. All real processes, as a rule, are irreversible. It means that entropy of an isolated system always grows. Growth of entropy shows system transition from less probable states to more probable one, i.e. to an equilibrium state.

However fluctuations are also possible. The law of entropy increase in an isolated system has a static character.

Thermodynamics second law (5.10) expressed mathematically is in accordance with all formulations considered previously.

Having analyzed thermal machines operation one can say that not all energy in the form of heat δQ can be transferred to the system for carry out work δA but only its part $\delta A = \eta \delta Q = (1 - \frac{T_2}{T_1}) \delta Q = \delta Q - T_2 \frac{\delta Q}{T_1} = \delta Q - T_2 dS$. The less the part is the more entropy is. This circumstance characterizes entropy as a measure working capacity. The increase of entropy of a system entropy is a characteristic sign of natural processes and corresponds to decline of energy quality. An isolated system always passes into a condition of thermodynamic balance in which entropy reaches its maximum value, and energy "depreciates".

6 Lecture №6. Electrostatic field in vacuum

Lecture content: fundamental concepts of electrostatic field and the main theorems for electrostatic field are briefly given in lecture.

Lecture objectives: to study of properties and characteristics of an electric charge and the methods of calculation of the electrostatic field.

6.1 Electric charge

Electric charge of a particle is one of its main characteristics defining the intensity of electromagnetic interactions. It has following properties:

- electric charge exists in two types: positive and negative. So, electrons have a negative charge and nucleus has a positive charge in atoms;
- electric charge is relativistic invariant: it does not change when a charge carrier moves, i.e. its value does not depend on a frame reference;
- electric charge is additive: the charge of any system is always equal to the algebraic sum of charges of particles in a system;
- electric charge is discrete, i.e. any charge is multiple to an elementary charge e : $q = \pm Ne$, where $e = 1,6 \cdot 10^{-19}$ C. This property is called quantization of electric charges. An electron and proton are carriers of elementary charges negative and positive respectively;
- the algebraic sum of all electric charges in any isolated system is constant. This property is called electric charge conservation law.

These properties are fundamental laws, they are not derived from any other laws. No phenomena contracting these properties were revealed.

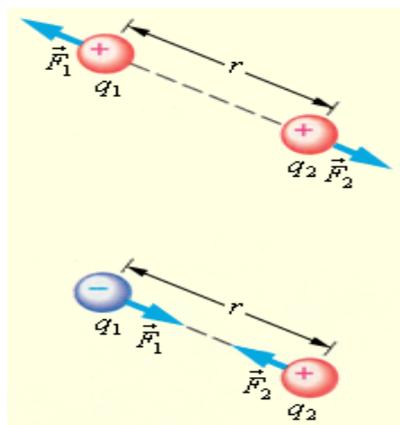
6.2 Electrostatic field. Characteristics of electrostatic fields

Interaction between electrically charged particles and bodies, according to modern representations, occurs due to the field. Electric field of motionless electric charges is called an electrostatic field. Forces acting on charged particles from an

electrostatic field are called electrostatic forces. A model of point charge is used in electrostatics similar to a material point (physical abstraction). A point charge is a charged body, the size of which can be neglected in comparison with the distances from this body to other charged bodies counted from their centers.

Interaction force of two point charges in vacuum obeys Coulomb's law: *interaction force between two motionless charges is directly proportional to product of modules of the charges and is inversely proportional to distance in a square between these charges* (Figure 6.1).

$$F = k \frac{|q_1||q_2|}{r^2}, \quad (6.1)$$



where q_1, q_2 - motionless point charges;
 r - distance between charges;

$$k = \frac{1}{4\pi\epsilon\epsilon_0} \text{ - coefficient of proportionality;}$$

$$\epsilon_0 = 8,85 \cdot 10^{-12} \frac{C^2}{N \cdot m^2} \text{ - electric constant.}$$

An electrostatic field intensity in a given point is a physical quantity determined by a force acting on a single positive charge placed in this point of the field

Figure 6.1

$$\vec{E} = \frac{\vec{F}}{q}. \quad (6.2)$$

The direction of a vector of intensity coincides with the direction of the force acting on a positive test charge.

The experience shows that the principle of independence of forces action is applied to electrostatic coulomb forces. Therefore, the resulting force acting on a test charge q_0 in any point of the field is equal to vector sum of forces applied to it from each charge q_i of the system

$$\vec{F} = \sum_{i=1}^n \vec{F}_i. \quad (6.3)$$

Taking into account (6.2) for intensity of a field \vec{E} , created by a system of charges, we will receive

$$\vec{E} = \sum_{i=1}^n \vec{E}_i. \quad (6.4)$$

Equation (6.4) expresses *the principle of superposition* (imposing) of electric fields.

7 Lecture №7. The main theorems of an electrostatics in vacuum

Lecture content: Fundamental concepts of an electrostatic field and the main theorems for electrostatic field are briefly given in lecture.

Lecture objectives: to study properties and characteristics of an electric charge as well as methods of calculation of the electrostatic field, work and potential in electrostatic field, relation of electric field intensity with its potential.

7.1 Work and potential in electrostatic field. Relation of electrostatic field intensity with its potential

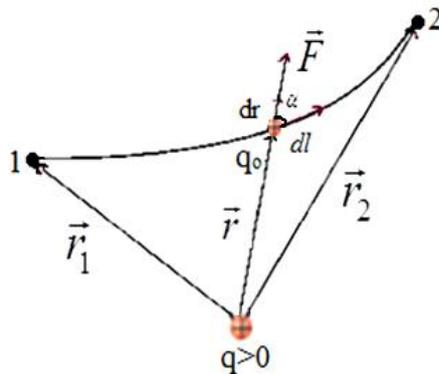


Figure 7.1

Let the point charge q_0 moves from point 1 to point 2 along a trajectory in an electrostatic field created by a motionless charge q (figure 7.1).

In this case the force applied to charge q_0 from the field makes work

$$A_{12} = \int_1^2 \vec{F} d\vec{l} = \int_1^2 F dl \cos \alpha,$$

where α – the angle between vectors of \vec{F} and displacement $d\vec{l}$.

Using Coulomb's law and ratio $dl \cos \alpha = dr$

we will receive following expression:

$$A_{12} = \frac{qq_0}{4\pi\epsilon_0} \int_{r_1}^{r_2} \frac{dr}{r^2} = \frac{1}{4\pi\epsilon_0} \left(\frac{qq_0}{r_1} - \frac{qq_0}{r_2} \right). \quad (7.1)$$

From ratio (7.1) it follows that work does not depend of a displacement trajectory (or a path) and is only defined by initial 1 and final 2 positions of a charge q_0 . Therefore an electrostatic field is potential and electrostatic forces are conservative.

Consequently work of the forces of an electrostatic field is equal to the decrease of potential energy and can be written down as:

$$A_{12} = \frac{1}{4\pi\epsilon_0} \frac{qq_0}{r_1} - \frac{1}{4\pi\epsilon_0} \frac{qq_0}{r_2} = W_{p_1} - W_{p_2} = -\Delta W_p. \quad (7.2)$$

A potential of an electrostatic field is equal to the ratio of potential energy W_p of a test point charge placed in the considered point of the field to this charge q_0

$$\varphi = \frac{W_p}{q_0}. \quad (7.3)$$

The work made by the forces of a field when charge q_0 moves from point 1 with potential φ_1 to point 2 with a potential φ_2 is equal

$$A_{12} = q_0(\varphi_1 - \varphi_2). \quad (7.4)$$

There exists an interaction between the field intensity, its force characteristic and the potential, its power characteristic, due to the potentiality of an electrostatic field. It is known that potential energy and force are interconnected in the field of potential forces as:

$$\vec{F} = -gradW_p = -\nabla W_p. \quad (7.5)$$

In an electric field this interrelation is expressed $\vec{E} = -grad\varphi$, or $\vec{E} = -\nabla\varphi$, where ∇ – the operator of a nabla, it can be written as:

$$\nabla = \vec{i} \frac{\partial}{\partial x} + \vec{j} \frac{\partial}{\partial y} + \vec{k} \frac{\partial}{\partial z}. \quad (7.6)$$

The sign "minus" indicates the direction of vector \vec{E} . It is always directed towards the decrease of potential (figures 7.2 and 7.3).

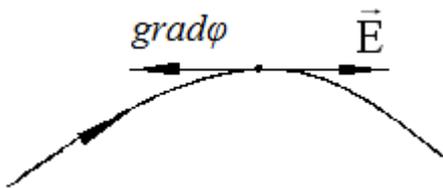


Figure 7.2

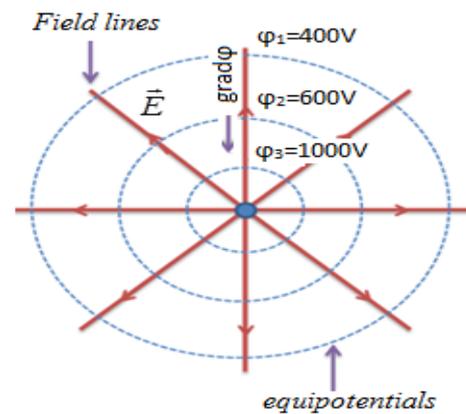


Figure 7.3

7.2 Theorem of circulation of vector \vec{E}

An electrostatic field represents a field of motionless charges. It is conservative, i.e. the work of forces of this field does not depend on the path, but it depends on initial and final positions of a charge. If to take a single positive charge

as a test charge the work of forces when it moves from a point 1 to a point 2 will be equal to $\int_1^2 \vec{E} d\vec{l}$. In this case the work on a random closed way is equal to zero

$$\oint_L \vec{E} d\vec{l} = 0. \quad (7.7)$$

Integral $\oint_L \vec{E} d\vec{l}$ is called a circulation of intensity vector \vec{E} . Thus, a vector circulation of electrostatic field intensity along any closed contour is equal to zero. Statement (7.7) is called theorem of circulation of vector \vec{E} . Force field having property (7.7) is called potential. The formula (7.7) is valid for an electrostatic field.

From the ratio for a circulation of electrostatic field intensity vector \vec{E} follows that lines of intensity of an electrostatic field cannot be closed.

7.3 Flux of a vector \vec{E} . Gauss's theorem

The main objective of electrostatics is to find characteristics of a field: field intensity E and potential φ by given values and distribution of charges in space. It is possible to solve this problem using the principle of superposition or Gauss's theorem.

The flux of electric field intensity through surface S , being in this field, can be expressed:

$$\Phi = \int_S \vec{E} d\vec{S} = \int_S E dS \cos \alpha = \int_S E_n dS, \quad (7.8)$$

where E_n – vector projection \vec{E} on normal \vec{n} towards elementary platform dS .

This value is algebraic. It depends not only on a field configuration but also on a choice of normal n direction towards platform S . In case of closed surfaces normal n is directed outside the area covered by this surface.

Flux of vector \vec{E} through random closed surface S depends only on the algebraic sum of charges covered by this surface

$$\oint_S \vec{E} d\vec{S} = \frac{1}{\epsilon_0} \sum_i q_i. \quad (7.9)$$

Formula (7.9) expresses Gauss's theorem for an electrostatic field in vacuum: flux of vector of electrostatic field intensity in vacuum through a random closed surface is equal to algebraic sum of charges concluded in this surface divided by electric constant ϵ_0 .

The Gauss's theorem (7.9) testifies that sources of an electrostatic field are electric charges.

8 Lecture №8. Electrostatic field in a substance. Energy of electric field

Lecture content: the main characteristics of an electrostatic field in substance and as well as energy of electric field are briefly given in the lecture.

Lecture objectives: to study the phenomenon of polarization of dielectrics and Gauss's theorem for a field in substance, to study energy of an electric field.

8.1 Dielectrics. Polarization of dielectrics

Dielectrics are substances which don't almost conduct electric current in usual conditions.

Molecules of dielectrics are neutral electrically and represent systems with total charge equal to zero. Despite this fact molecules have electric properties and at the first approximation one molecule can be considered as an electric dipole.

The positive charge of such a dipole is equal to total charge of nuclei. It is placed in "the center of gravity" of positive charges. The negative charge is equal to total charge of electrons and is placed in "the center of gravity" of negative charges. Electric moment of such a dipole is $\vec{p} = q\vec{l}$ (q is total positive charge of all nuclei in a molecule, \vec{l} is a vector carried from "the center of gravity" of electrons to "the center of gravity" of positive of nuclear charges).

The placement of dielectrics into an external electric field causes an electric moment of a dielectric which is different from zero. In this case the dielectric is polarized.

Polarization of a dielectric is the appearance of dipoles oriented along the field due to an external electric field. Therefore, the electric moment of some dielectric volume differs from zero.

Dielectrics are divided into three groups: polar, nonpolar and crystal. According to these three groups of dielectrics there are three types of polarization: electronic (deformation) at nonpolar dielectrics, orientational (dipolar) at polar dielectrics and ionic at dielectrics with ionic crystal lattices.

8.2 Polarizability. Volume and surface bound charges

Quantitative measure of dielectric polarization is vector \vec{P} . It is called polarizability (or polarization vector) and equal to the ratio of electric dipolar moment of physically infinitesimal volume of a dielectric to this volume

$$\vec{P} = \frac{1}{\Delta V} \sum_i \vec{p}_i, \quad (8.1)$$

where \vec{p}_i – dipolar moment of one molecule.

Isotropic dielectrics have polarizability of any type connected with field intensity at the same point by a simple ratio

$$\vec{P} = \epsilon_0 \chi \vec{E}, \quad (8.2)$$

where χ – the dielectric susceptibility of a dielectric, dimensionless value characterizing the ability of a dielectric to polarization.

Within a small volume all molecules of a nonpolar dielectric get (figure 8.1a) identical electric moments \vec{p}_e in an electric field, therefore polarization is equal to $\vec{P} = n\vec{p}_e$ (n – concentration of molecules).

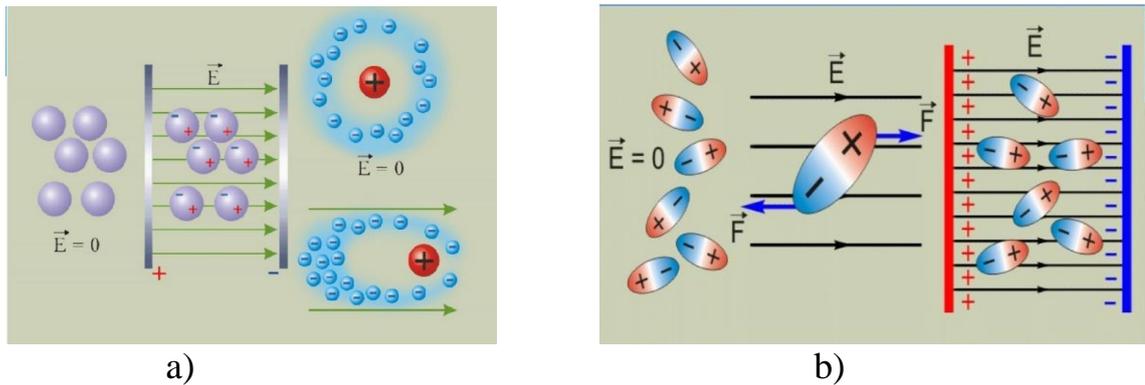


Figure 8.1

In the case of polar dielectrics thermal motion of molecules tends to scatter their dipolar moments in all directions and prevents the action of an external field (figure 8.1b). As a result some preferred orientation of molecules dipolar moments is established in the direction of the field. Calculation and experiments are expressed in formula (8.2).

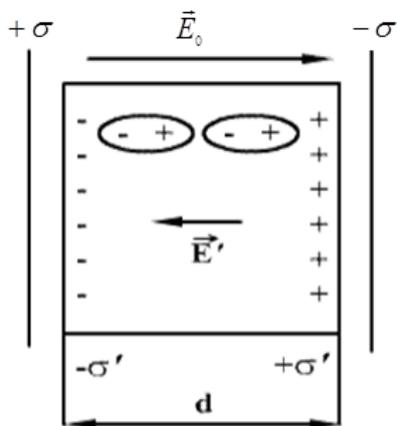


Figure 8.2

The relation between \vec{E} and \vec{P} is nonlinear and depends on the previous values \vec{E} (this phenomenon is called a hysteresis).

From figure 8.2 it follows that while placing a dielectric into an external field its polarization occurs, i.e. positive charges are displaced along a field, negative – against a field. As a result excess positive charges with surface density $+\sigma$ (on the right) and negative ones with surface density $-\sigma$ (on the left) appears on crystal faces of dielectric plate. These charges are called *superficial bound (polarizational)*. They are a part of atoms and molecules of a dielectric and cannot leave their limits.

There is a simple relation between polarizability \vec{P} and surface density of the bound charges σ :

$$\sigma = P \cos \alpha = P_n . \quad (8.3)$$

Taking into account (7.2) we will come to the formula:

$$\sigma = P_n = \varepsilon_0 \chi E_n , \quad (8.4)$$

where P_n – polarizability projection onto an external normal to a given point of the surface;

E_n – projections of field intensity onto the same normal.

Bound charges differ from free ones as they can't leave the limits of molecules. For the rest they have the same properties, as others, in particular, they are sources of electric fields.

8.3 Vector of electric displacement. Gauss's theorem for an electrostatic field in dielectric

It was noted that the sources of a field are not only free charges, but also bound charges. Therefore Gauss's theorem for field \vec{E} can be written down as

$$\oint_S \vec{E} d\vec{S} = \frac{1}{\varepsilon_0} (\sum_i q_i + \sum_i q'_i), \quad (8.5)$$

where $\left(\sum_i q_i + \sum_i q'_i \right)$ – algebraic sum of free and bound charges covered by surface S .

Formula (8.5) is not used for finding vector \vec{E} because the distribution of bound charges is not known in advance.

Calculation of fields becomes simpler in many cases with introduction of an auxiliary value. It describes only the sources of free charges. It is called *electric displacement or electric induction*

$$\vec{D} = \varepsilon_0 \vec{E} + \vec{P} . \quad (8.6)$$

It should be noted that vector \vec{D} represents the sum of two absolutely different values: $\varepsilon_0 \vec{E}$ and \vec{P} . Therefore it is really an auxiliary vector. It hasn't any physical meaning, but in many cases its introduction simplifies studying a field in dielectrics.

Vector flux \vec{D} through a random closed surface is equal to algebraic sum of free charges covered by this surface

$$\oint_S \vec{D} d\vec{S} = \sum_i q_i . \quad (8.7)$$

It is Gauss's theorem for vector \vec{D} .

Using expression (8.4) for \vec{P} in (8.6), we will receive

$$\vec{D} = \varepsilon_0 \vec{E} + \varepsilon_0 \chi \vec{E} = \varepsilon_0 (1 + \chi) \vec{E} \quad \text{or} \quad \vec{D} = \varepsilon_0 \varepsilon \vec{E}, \quad (8.8)$$

where $\varepsilon = 1 + \chi$ – the dielectric permeability of substance being the main electric characteristic of a dielectric.

8.4 Boundary conditions for two dielectrics

Behavior of vectors \vec{E} and \vec{D} on interface of two uniform isotropic dielectrics are defined with the help of the main theorems of electrostatics: theorem of vector circulation \vec{E} (7.7) and Gauss's theorem for a vector \vec{D} (8.7). There are expressed as:

$$\oint_L \vec{E} d\vec{l} = 0, \quad \oint_S \vec{D} d\vec{S} = \sum_i q_i.$$

According to the theorem of vector circulation \vec{E} and relation between vector \vec{E} with vector \vec{D} we can receive

$$E_{1\tau} = E_{2\tau}, \quad \frac{D_{1\tau}}{D_{2\tau}} = \frac{\varepsilon_1}{\varepsilon_2}, \quad (8.9)$$

i.e. tangential component of vector \vec{E} is identical on both sides of the boundary section and doesn't have a bend. Tangential components of vector \vec{D} have a bend while crossing the boundary. From Gauss's theorem we have

$$D_{1n} = D_{2n}, \quad \frac{E_{1n}}{E_{2n}} = \frac{\varepsilon_2}{\varepsilon_1}. \quad (8.10)$$

From expression (8.10) it follows that when crossing the boundary normal component \vec{D} doesn't change, and normal component \vec{E} has a bend.

Received conditions for vectors \vec{E} and \vec{D} on boundary of two dielectrics (8.9) and (8.10) mean that lines of these vectors refract themselves and angle α between the normal to the interface and line \vec{E} changes (figure 8.3).

With regard to received conditions the law of refraction of lines of electrostatic field intensity on the interface of two dielectrics is expressed by the formula at absence of free charges on that surface:

$$\frac{\text{tg} \alpha_2}{\text{tg} \alpha_1} = \frac{\varepsilon_2}{\varepsilon_1}. \quad (8.11)$$

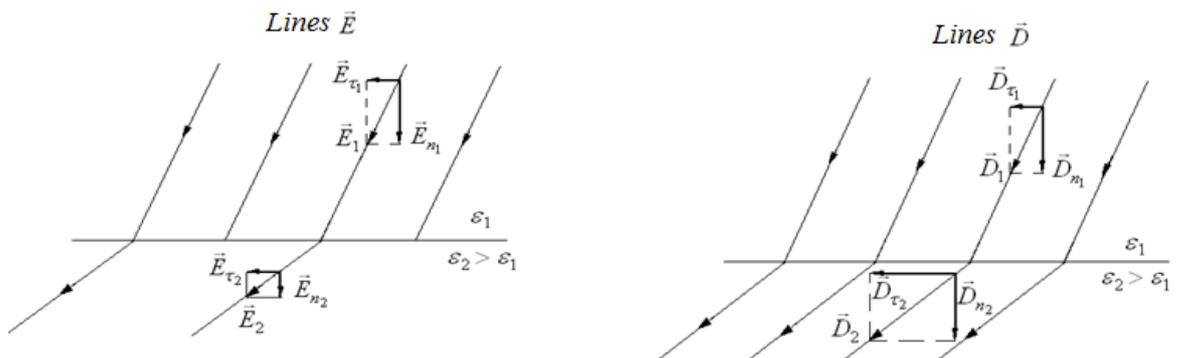


Figure 8.3 – Refraction of vectors \vec{E} and \vec{D} on the boundary of two dielectric materials ($\epsilon_2 > \epsilon_1$)

8.5 Energy of electric field

8.5.1 Energy of interaction of a system of charges.

Quantitatively the energy of interaction is equal to the work made by interaction forces when all particles of the system move on infinite distances from each other. If in a system of particles the energy of each particle in the field of another one is equal to W_{12} and W_{21} , it is obvious that $W_{12}=W_{21}=W_p$. Therefore potential energy of interaction of two particles can be expressed $W_p = \frac{1}{2}(W_{12} + W_{21})$.

Consequently the energy of interaction of a system of many particles can be written down

$$W_p = \frac{1}{2} \sum_{i=1}^n W_{pi},$$

where W_{pi} – potential energy of i -y of a particle in fields of all other particles of the system.

For the system of interacting point charges with regard to defining potential (8.6) we will receive

$$W_p = \frac{1}{2} \sum_{i=1}^n q_i \varphi_i, \quad (8.12)$$

where φ_i – full potential created by all other charges of the system in the point of location of charge q_i .

8.5.2 Energy of secluded conductor and condenser.

Let a conductor have charge q and potential φ . Since the surface of the conductor is equipotential therefore, energy of the secluded conductor can be expressed:

$$W_p = \frac{q\varphi}{2} = \frac{q^2}{2C} = \frac{C\varphi^2}{2}. \quad (8.13)$$

Energy of a charged conductor is equal to the work of external forces when charging.

For the energy of charged condenser this formula is valid:

$$W_p = \frac{q^2}{2C} = \frac{CU^2}{2} = \frac{qU}{2}. \quad (8.14)$$

8.5.3 Energy of electric field.

Let's consider a charged flat condenser. Its energy is defined by formulas (8.14) and ratio for electric capacity by:

$$C = \frac{\varepsilon_0 \varepsilon S}{d}. \quad (8.15)$$

If distance d between plates of a condenser is much less than their sizes the electric field in the condenser can be considered uniform. If expression $U = E \cdot d$ and (8.15) will be put into (8.14) we can receive

$$W_p = \frac{\varepsilon_0 \varepsilon E^2}{2} \cdot S \cdot d = \frac{\varepsilon_0 \varepsilon E^2}{2} V, \quad (8.16)$$

where $V = S \cdot d$ – the volume where an electric field of the flat condenser is concentrated.

Taking into consideration (8.16) it is possible to receive formulas of energy density of an electric field

$$\omega = \frac{W_p}{V} = \frac{\varepsilon_0 \varepsilon E^2}{2} = \frac{D^2}{2\varepsilon_0 \varepsilon} = \frac{ED}{2}. \quad (8.17)$$

If we know the density of energy of a field in each point it is possible to find the energy of the field concluded in any volume V :

$$W = \int_{VV} \omega \cdot dV = \int \frac{\varepsilon_0 \varepsilon E^2}{2} dV. \quad (8.18)$$

Formula (8.18) is universal and applied to calculate uniform and non-uniform electrostatic field, as well as variables of not potential fields.

9 Lecture №9. Direct electric current

Lecture content: the main condition of existence of direct electric current, the classical theory of conductivity of metals and concluded from it fundamental laws of electric current are briefly given in the lecture.

Lecture objectives: to study the main characteristics of direct current, and methods of calculation of electric circuit.

9.1 General characteristics and current conditions

An ordered movement of charged particles or macroscopic bodies is called *an electric current*.

Electric current of conductivity is an ordered movement in substance or in vacuum of free charged particles – current carriers.

Convictional electric current is electric current formed by a moving charged macroscopic body.

Current conditions are the existence in a medium of current carriers and as well as an electric field.

To conduct current flow it is necessary to have a source of electric energy for transforming any form of energy to energy of electric current.

The measure of electric current is amperage I . It is a scalar physical quantity determined by an electric charge passing through considered surface in a unit of time

$$I = \frac{dq}{dt}. \quad (9.1)$$

If current and its direction do not change in time such current is called *direct current* and equal to: $I = \frac{q}{t}$.

The constancy of electric field intensity in all points of a conductor is necessary for stability of electric current. Therefore, charges should not collect or decrease somewhere in this conductor. This condition means that a circuit of direct current has to be closed and current must be the same in all cross sections of the circuit.

To characterize the direction of electric current in different points of a considered surface and distribution of current on it the vector of current density is introduced.

The physical quantity determined by current passing through a unit of surface area perpendicular to the direction of current is called *a density of current*

$$j = \frac{dI}{dS_{\perp}}. \quad (9.2)$$

From expression (9.2) it follows that current passing through any surface S is equal to the flux through this surface of density current vector

$$I = \int_S \vec{j} d\vec{S}. \quad (9.3)$$

Current density can be expressed by velocity $\langle \vec{v} \rangle$ of an ordered movement of charges in conductor, and concentration of current carriers n and as well as elementary charge q

$$\vec{j} = q \cdot n \cdot \langle \vec{v} \rangle. \quad (9.4)$$

9.2 Continuity equation. Condition of electric current stationary

Let's consider closed surface S in a conductive medium where current flows. According to (9.3) the vector flux of current density through this surface is equal to the current going out off the area limited by this surface. According to the conservation law of a charge this integral is equal to a charge decreasing in a unit of time within in a limited volume

$$\oint_S \vec{j} d\vec{S} = - \frac{dq}{dt}. \quad (9.5)$$

Ratio (9.5) is called *the continuity equation*.

In the case of stationary (direct) current the distribution of charges in space is invariable. Therefore, we can receive expression $\oint \vec{j} d\vec{S} = 0$. Consequently the lines of vector \vec{j} do not begin anywhere and do not end anywhere, they are closed, i.e. vector field \vec{j} has no sources.

9.3 Classical electronic theory of conductivity of metals

Experiments of K. Rikke (1901), S. L. Mandelstam and N. D. Papaleksi (1913), R. Tolmen and B. Stewart (1916) showed that current carriers in metals are free electrons. They are the electrons weakly connected with ions of a crystal lattice of a metal. Concentration of free electrons has values approximately $n = (10^{28} \div 10^{29}) m^{-3}$.

According to the idea of free electrons, P. Drude and H. Lorentz created a classical theory of metals. It is supposed in Drude-Lorentz's theory that:

- electrons of conductivity behave like molecules of an ideal gas;
- average speed of thermal movement of electrons can be determined by formula $\langle u \rangle = \sqrt{8kT / \pi m_e}$;
- electrons collide with ions forming a crystal lattice of a metal. It results in setting up thermal balance between an electronic gas and a crystal lattice;
- average time of electrons free run τ is determined by formula:

$$\langle \tau \rangle = \frac{\langle l \rangle}{\langle u \rangle}, \quad (9.6)$$

where $\langle l \rangle$ – average length of electrons free run;

$\langle u \rangle$ - average speed of their thermal movement;

while colliding with ions the electrons completely lose the speed of the ordered movement, transferring acquired energy to the lattice, increasing internal energy of a metal; the latter heats up;

– electric resistance of metals is caused by collisions of free electrons with ions.

Taking into account the information mentioned above one can derive Ohm's and Joule Lenz's laws in a differential form.

Ohm's law. Let a free electron be accelerated by an electric field in the conductor. In this case the equation of its movement is:

$$ma = eE,$$

where m – mass of an electron;

a – acceleration of an electron;

e – electron charge.

Since the movement of an electron is uniformly accelerated, the average speed of ordered movement of electrons is expressed:

$$\langle \vec{v} \rangle = \frac{e \langle l \rangle \vec{E}}{2m \langle u \rangle}, \quad (9.7)$$

and the current density is equal to

$$\vec{j} = \frac{ne^2 \vec{E} \langle l \rangle}{2m \langle u \rangle}. \quad (9.8)$$

Expression

$$\gamma = \frac{ne^2 \langle l \rangle}{2m \langle u \rangle} \quad (9.9)$$

is called a *specific electric conductivity*. Its opposite value $\rho = \frac{1}{\gamma}$ is a *specific electric resistance* of a conductor. Therefore,

$$\vec{j} = \gamma \vec{E} = \frac{1}{\rho} \vec{E}. \quad (9.10)$$

Equation (9.10) expresses Ohm's law in a differential form.

Joule Lenz's law. At each collision an electron transfers to an ion in a lattice the average energy given to it by an electric field

$$\langle W_k \rangle = \frac{1}{2} m \langle v_{\max} \rangle^2 = \frac{1}{2} \frac{eE^2 \langle l \rangle^2}{m \langle u \rangle^2}. \quad (9.11)$$

Frequency of collisions of each electron with atoms is equal to $\frac{\langle u \rangle}{\langle l \rangle}$ and for a number of electrons n it is equal to $n \frac{\langle u \rangle}{\langle l \rangle}$. Therefore, the volume density current of thermal power is defined by expression

$$\omega = \frac{ne^2 \langle l \rangle E^2}{2m \langle u \rangle} \quad (9.12)$$

or

$$\omega = \gamma E^2. \quad (9.13)$$

Equation (9.13) expresses Joule Lenz's law in a differential form.

Despite presentation and effectiveness of dependence of current density and an amount of warmth developed from field intensity, the classical theory of conductivity does not lead to correct quantitative results. The main divergences of the theory with experiment are as follows:

– experiment for dependence of conductivity on temperature leads to law $\gamma \sim \frac{1}{T}$ but from formula (9.9) it follows that $\gamma \sim \frac{1}{\sqrt{T}}$ because according to the kinetic theory of gases we know that $\langle u \rangle \sim \sqrt{T}$;

– according to the theorem of equal distribution of energy by degrees of freedom one should expect large contribution to a thermal capacity of conductors by free electrons, but that is not observed in experiments.

The specified difficulties are overcome in the quantum theory considering wave properties of micro particles.

10 Lecture №10. Magnetic field in vacuum

Lecture content: fundamental concepts of magnetic field and the main theorems for magnetic field are briefly given in lecture.

Lecture objectives: to study the main characteristics of magnetic field and to understand main methods of magnetic field calculation.

10.1 Magnetic field. Vector of magnetic induction

A force field created by magnets is called a magnetic field. A source of a constant magnetic field is stationary electric currents. The field of permanent

magnets is also created by currents. They are microscopic currents (molecular currents). Generally it is possible to claim that there is a magnetic field around any moving charge. Magnetic charges don't exist in nature.

Power characteristic of a magnetic field is vector \vec{B} . It is called magnetic induction of a field. Magnetic induction \vec{B} is equal to the ratio of force acting on a charged particle from a magnetic field to the product of an absolute value of the charge and a particle velocity. The direction of a particle velocity has to be such that this force is maximum

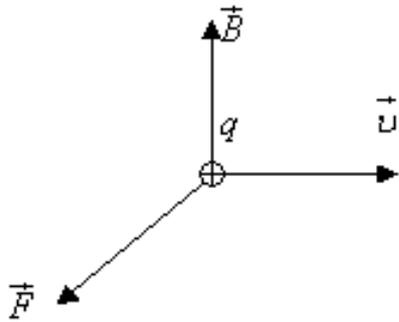


Figure 10.1

$$B = \frac{F_{\max}}{|q| \cdot v}, \quad (10.1)$$

in this case vectors $\vec{B}, \vec{F}, \vec{v}$ form the right screw or right-handed (figure 10.1).

A magnetic field is called uniform if in all its points the vectors of magnetic induction are identical both in module and direction. Otherwise the magnetic field is called non-uniform.

For graphic representation of a stationary magnetic field we use the method of lines of magnetic induction. The lines are drawn so that tangent to the lines of magnetic induction coincide with the direction of vector \vec{B} in this point of the field.

10.2 Principle of superposition. Biot-Savart-Laplace's law

Principle of superposition. Results of experiments show that the magnetic field created by several moving charges or currents is equal to vector sum of magnetic fields created by each moving charge or current separately

$$\vec{B} = \sum_{i=1}^N \vec{B}_i. \quad (10.2)$$

Biot-Savart-Laplace's law allows to calculate magnetic induction in each point of the field created by the current flowing in a conductor of any form. According to this law magnetic induction of direct electric current I in vacuum has to satisfy the equation:

$$d\vec{B} = \frac{\mu_0}{4\pi} \cdot \frac{I [d\vec{l} \vec{r}]}{r^3}, \quad (10.3)$$

where $d\vec{B}$ – magnetic induction of a magnetic field created by current element;

$I d\vec{l}$ - current element, which direction coincides with the direction of a current density vector;

\vec{r} - the radius vector which is drawn from this element to considered point C of a field;

$\mu_0 = 4\pi \cdot 10^{-7}$ H/m - magnetic constant;

I - current in the conductor (figure 10.2).

In point C vector $d\vec{B}$ is directed perpendicular to the plane of vectors $d\vec{l}$ and \vec{r} by the right screw rule.

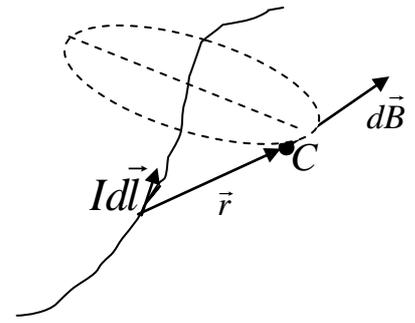


Figure 10.2

10.3 Magnetic flux. Fundamental laws of a magnetic field

A magnetic field has two major properties. These properties connected with a flux and circulation of vector field \vec{B} express fundamental laws of a magnetic field.

Magnetic flux through a small surface of area dS is called physical quantity $d\Phi$ and expressed

$$d\Phi = \vec{B} d\vec{S} = B_n dS = B dS \cos (\vec{B} \wedge \vec{n}), \quad (10.4)$$

where $d\vec{S} = \vec{n} dS$;

\vec{n} - single vector of a normal to platform dS ;

B_n - vector projection \vec{B} on the direction of the normal.

Magnetic flux through a random surface is equal:

$$\Phi = \int_S \vec{B} d\vec{S} = \int_S B_n dS. \quad (10.5)$$

Gauss's theorem for field \vec{B} : the flux of magnetic induction vector through a closed surface is equal to zero. This law expresses the fact that there are no magnetic charges in the nature. A magnetic field has no of sources, therefore we have

$$\oint_S \vec{B} d\vec{S} = 0. \quad (10.6)$$

Circulation of vector \vec{B} on a random contour for a magnetic field of direct currents is equal to the product μ_0 by the algebraic sum of currents covered by this contour

$$\oint_L \vec{B} d\vec{l} = \mu_0 \sum_{i=1}^N I_i. \quad (10.7)$$

From expression (10.7) it follows that in contrast an electrostatic field a magnetic field is vortical. The practical aspect of the theorem of circulation of magnetic induction is that we can count magnetic fields created by some configurations of electric currents.

10.4 Work of moving current-carrying conductor in a constant magnetic field

The elementary work made by forces of a magnetic field while a closed circuit with current moves in a magnetic field is equal to product of current by the change of a magnetic flux through the surface limited by this circuit

$$dA = Id\Phi . \quad (10.8)$$

Total work of forces of a magnetic field at the movement of circuit carrying current from initial position 1 to final 2 can be determined by formula

$$A = \int_1^2 Id\Phi . \quad (10.9)$$

In the case of a direct current it is equal to

$$A = I(\Phi_2 - \Phi_1) = I\Delta\Phi . \quad (10.10)$$

10.5 Hall's effect

Hall's effect is an emergence of the electric field \vec{E} in a metal with current density \vec{j} , placed in magnetic field \vec{B} . Direction of electric field \vec{E} is perpendicular \vec{B} and \vec{j} . It is schematically shown in figure 10.3. The value of the arising electric field can be determined by potential difference $|\Delta\varphi| = E \cdot a$. It is experimentally shown that

$$|\Delta\varphi| = R \frac{IB}{d} = RjBa . \quad (10.11)$$

This expression represents Hall's transverse potential difference.

The emergence of transverse potential difference $\Delta\varphi$ is caused by the following reason. Lorentz force acts from the magnetic field on ordered moving carriers of current in the conductor (in figure 10.3 electrons are represented), therefore particles deviate and form the transverse difference of potential.

Using the electronic theory of conductivity, one can show that the Hall's constant R in formula (10.12) is equal to

$$R = \frac{1}{en} , \quad (10.12)$$

where e – an electron charge;

n – concentration of current carriers (electrons) in substance.

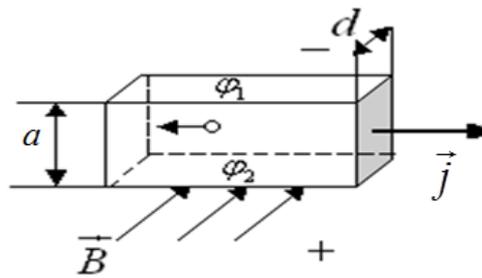


Figure 10.3

11 Lecture №11. Magnetic field in substance

Lecture content: the main characteristics of a magnetic field in substance are briefly given in lecture.

Lecture objectives: to study the phenomenon of magnetization of substance; to understand the main methods of calculation of magnetic fields in substance.

11.1 Magnetization of substance. Vector of magnetizability

Any substance is a magnetic, i.e. it is capable to be magnetized by the influence of an external magnetic field and create the own magnetic field. The resulting field in substance is equal to the sum of induction of external and internal fields:

$$\vec{B} = \vec{B}_0 + \vec{B}', \quad (11.1)$$

where \vec{B}_0 – induction of an external field (field of currents of conductivity);

\vec{B}' – induction of the own (internal) field created by a magnetized substance.

Magnetization of a substance is caused by preferred orientation or induction of magnetic moments of separate molecules in one direction. It is necessary to emphasize that substances which molecules in the lack of a field have no magnetic moment, are magnetized due to induction of elementary circular currents of molecules, therefore molecules and the whole substance get the magnetic moment.

Degree of magnetization of a magnetic is characterized by a magnetic moment of a volume unit and is called a vector magnetizability \vec{J} :

$$\vec{J} = \frac{1}{\Delta V} \sum_{i=1}^N \vec{p}_{mi}, \quad (11.2)$$

where ΔV – infinitesimal volume in the vicinities of a considered magnetic point;

\vec{p}_{mi} – magnetic moment of a separate molecule.

Summation is carried out in all molecules in volume ΔV .

Magnetizability of any element of volume is created by an external magnetic field, therefore \vec{J} depends on \vec{B}_0 . At the same time the magnetized substance creates field \vec{B}' . Therefore value \vec{B}' depends on \vec{J} .

Let's consider in a magnetized substance a small element of volume in the form of long cylinder which axis is parallel to the direction of magnetizability vector (figure 11.1a).

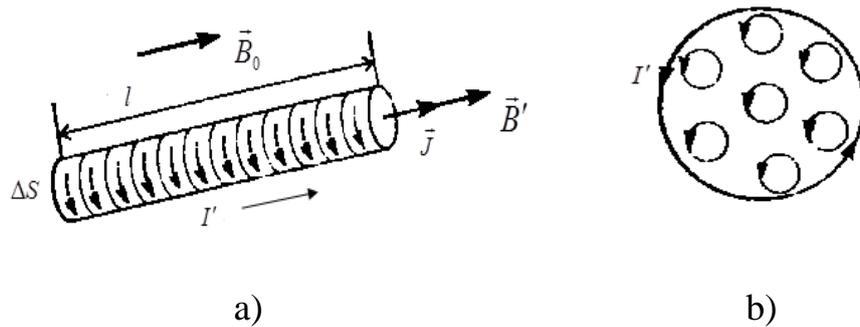


Figure 11.1

Elementary currents are presented on cylinder cross section (figure 11.1b). Action of a set of these magnetic moments can be formally replaced by the action of current formally I' , that is called the current of magnetization flowing around the surface of this cylinder. The magnetic moment of this small element of volume can be expressed in two ways

$$I' \cdot \Delta S = J \cdot \Delta S \cdot l. \quad (11.3)$$

So,

$$I' = J \cdot l. \quad (11.4)$$

Generally it is possible to show that total action of all micro-currents can be characterized by circulation of vector \vec{J}

$$I' = \oint \vec{J} d\vec{l}. \quad (11.5)$$

11.2 The main theorems of magnetostatics for a field in substance

Gauss's theorem. The field of a magnetized substance as well as a field of currents of conductivity has no sources, therefore Gauss's theorem can be written like for a field in vacuum

$$\oint_S \vec{B} d\vec{S} = 0. \quad (11.6)$$

Consequently the lines of vector \vec{B} remain continuous everywhere.

Theorem of circulation of a vector \vec{B} . In magnets circulation vector is defined both by currents of conductivity I and magnetization currents I' namely

$$\oint_L \vec{B} d\vec{l} = \mu_0 (I + I'). \quad (11.7)$$

Taking into account formula (11.5) we will receive

$$\oint_L \left(\frac{\vec{B}}{\mu_0} - \vec{J} \right) d\vec{l} = I. \quad (11.8)$$

The value being under integral sign

$$\vec{H} = \frac{\vec{B}}{\mu_0} - \vec{J} \quad (11.9)$$

is called *intensity of a magnetic field*. It doesn't have a direct physical meaning but it helps to write in a convenient form equations for magnetic fields in non-uniform environments.

Theorem of circulation of vector \vec{H} : circulation of vector \vec{H} along any closed contour in any medium is equal to the algebraic sum of currents of conductivity covered by this contour

$$\oint_L \vec{H} d\vec{l} = \sum_{i=1}^N I_i. \quad (11.10)$$

The received ratio is called the law of a total current. This law is widely used to calculate magnetic fields in non-uniform medium.

There is a linear dependence between \vec{J} and \vec{H} :

$$\vec{J} = \chi \vec{H}, \quad (11.11)$$

where χ – magnetic susceptibility of a medium that is characteristic for each magnetic material.

Value χ can be different both positive and negative.

Magnetic materials that conform to dependence (11.11) are subdivided into paramagnetic materials ($\chi > 0$) and diamagnetic ones ($\chi < 0$). There are paramagnetic materials at $\vec{J} \uparrow \uparrow \vec{H}$ and diamagnetic materials at $\vec{J} \uparrow \downarrow \vec{H}$. Consequently for ferromagnetic materials dependence \vec{J} from \vec{H} has a difficult character: it is nonlinear and a hysteresis is observed, i.e. dependence \vec{J} from previous conditions of being a magnetic material.

Taking into consideration expression (11.11) one can receive the following formula for relation of vectors \vec{B} and \vec{H} :

$$\vec{B} = \mu_0 \mu \vec{H} , \quad (11.12)$$

where $\mu = 1 + \chi$ – magnetic permeability of a medium.

$\mu > 1$ in paramagnetic materials, $\mu < 1$ in diamagnetic materials and μ for dia- and paramagnetic materials differs a little from unit one, i.e. magnetic properties of these magnetic materials are weakly expressed.

We can refer such substances to *paramagnetic materials* which are magnetized in an external magnetic field in the direction of vector \vec{B} . Atoms (molecules or ions) of a paramagnetic materials have own magnetic moment \vec{p}_m . They include alkaline and alkaline-earth metals, oxygen, chloride iron, and others. Without a magnetic field paramagnetic materials is not magnetized since the total magnetic moment of molecules is equal to zero.

It is possible to refer such substances to *diamagnetic materials* which are magnetized in an external magnetic field in the direction opposite to the direction of a vector of magnetic induction \vec{B} . The magnetic moments of atoms, molecules or ions in the absence of an external magnetic field are equal to zero. Diamagnetic materials are inert gases, copper, gold, water (liquid), silver and other substance. In a magnetic field atoms (a substance molecules) have induced magnetic moments.

Ferromagnetic materials are solid substances possessing spontaneous magnetization which strongly changes under the external influence: magnetic field, deformation and also temperature change. An internal magnetic field in ferromagnetic materials can surpass an external field in hundreds and thousands times. Crystals of transitional metals possess such properties (iron, cobalt, nickel), some rare-earth elements and a number of alloys, ferrite as well as some metal glasses.

11.3 Boundary conditions for a magnetic field. Calculation of magnetic fields in non-uniform medium

On the media boundary both characteristics of a magnetic field \vec{B} and \vec{H} explosively change in value and direction. Boundary conditions for vectors \vec{B} and \vec{H} are calculated by analogy with on electric field (lecture 7) and are expressed by formulas:

$$\begin{aligned} B_{1n} &= B_{2n} ; & \frac{H_{1n}}{H_{2n}} &= \frac{\mu_2}{\mu_1} ; \\ H_{1\tau} &= H_{2\tau} ; & \frac{B_{1\tau}}{B_{2\tau}} &= \frac{\mu_1}{\mu_2} . \end{aligned} \quad (11.13)$$

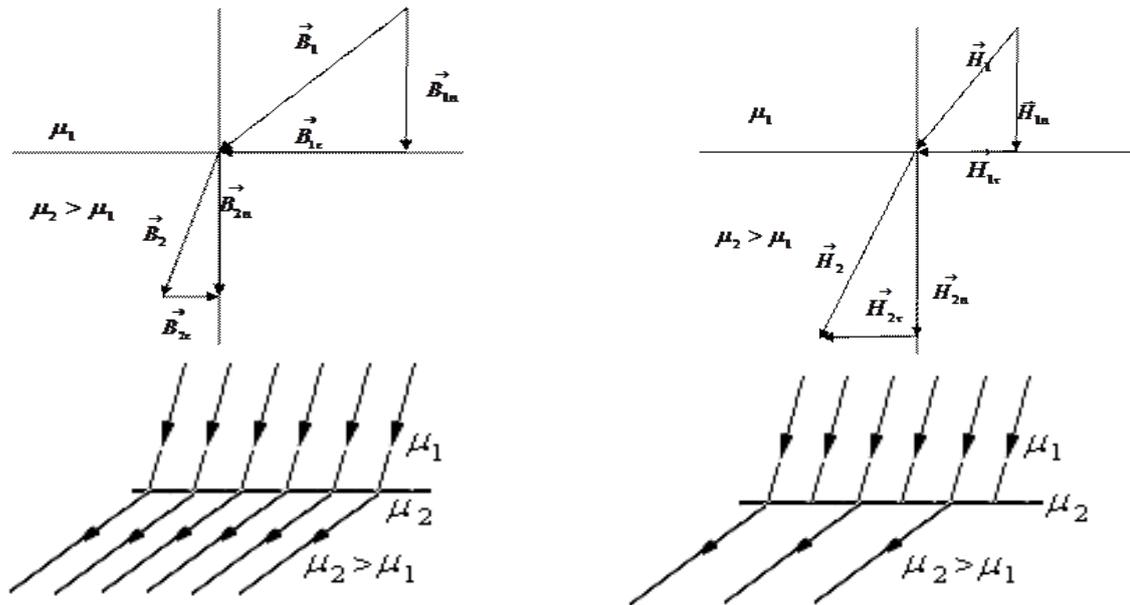


Figure 11.2 – Refraction of vectors \vec{B} and \vec{H} on the boundary of two magnetic materials ($\mu_2 > \mu_1$)

The received conditions for components of vectors \vec{B} and \vec{H} on boundary of two magnetic materials mean that lines of these vectors refract as a result angle α changes (figure 11.2).

Calculation of magnetic fields in non-uniform medium is performed by means of the law of total current and boundary conditions.

Literature

- 1 Varlamov A. The Wonders of Physics. - London: Word Scientific, 2012.
- 2 Young, Hugh D. Sears & Zemensky'S College Physics 1-v.- Boston: Addison-Wesley, 2012.- P. 586.
- 3 Young, Hugh D. Sears & Zemensky'S College Physics 2-v.- Boston: Addison-Wesley, 2012.- P.506.
- 4 Wolfson, Richard. Essential University Physics. 1Volume. - USA: Pearson, 2014.
- 5 Wolfson, Richard. Essential University Physics. 2 Volume. - USA: Pearson, 2014.
- 6 Савельев И.В. Курс физики.- М.: Кнорус, 2012.- Т.1-2.
- 7 Трофимова Т.И. Курс физики. - М.: Высш.школа, 2004.

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PHYSICS 1

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АЛМАТИНСКИЙ УНИВЕРСИТЕТ ЭНЕРГЕТИКИ И СВЯЗИ

Кафедра физики

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ФИЗИКА 1

Конспект лекций для студентов специальности
5В070200 – Автоматизация и управление
(на английском языке)

<p>СОГЛАСОВАНО: Начальник УМО _____ М.А. Мустафин " ____ " _____ 2016.</p> <p>Председатель ОУМК и МОиЭ _____ Б.К. Курпенов</p> <p>Редактор _____ " ____ " _____ 2016.</p> <p>Специалист по стандартизации _____ " ____ " _____ 2016.</p>	<p>Рассмотрено и одобрено на заседаний кафедры физики Протокол №1 от 22.09.2016г. Зав. кафедрой физики _____ М.Ш. Карсыбаев</p> <p>Согласовано: Зав.каф. ИК " ____ " _____ Б.К. Муханов</p> <p>Составители: _____ Л.Х. Мажитова _____ А.И. Кенжебекова _____ Г.К. Наурызбаева</p>
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