Physics. The Main Course

MECHANICS

KEY DEFINITIONS

- Mechanics - part of physics that studies the laws of mechanical motion and causes which change the movement.
- Mechanical movement - change in the relative positions of the bodies, or parts of them in the space over time.

TYPES OF MECHANICS

Mechanics

Classical Mechanics (Galiley-Newton)
Learning the laws of motion macroscopic bodies,
which velocities are small
compared with the rate
light in vacuum.
$v / c << 1$

Relativistic - studying the laws of motion macroscopic bodies with
speeds comparable to c.
Based on the SRT.

Quantum - Learning the laws of motion macroscopic bodies (Individual atoms and
elementary particles)

KINEMATICS, DYNAMICS, STATICS

- Kinematics (from the Greek word kinema - motion) - the section of mechanics that studies the geometric properties of the motion of bodies without taking into account their weight and acting on them forces.
- Dynamics (from the Greek dynamis - force) is studying the motion of bodies in connection with the reasons that cause this movement.

KINEMATICS, DYNAMICS, STATICS

- Statics (from the Greek statike - balance) is studying the conditions of equilibrium of bodies.
- Since the balance - is a special case of motion, the laws of statics are a natural consequence of the laws of dynamics and in this course is not taught.

MODELS IN MECHANICS

- Material - body size, shape and
- point of the internal structure which in this problem can be ignored

- Absolutely solid - body, which in any
- conditions of the body can not be deformed and under all circumstances the distance between two points of the body
- It remains constant

-
- Absolutely elastic - body, the deformation of which
- body obeys Hooke's law, and after
- termination of the external force takes its initial size and shape

SYSTEM AND BODY OF THE COUNTDOWN

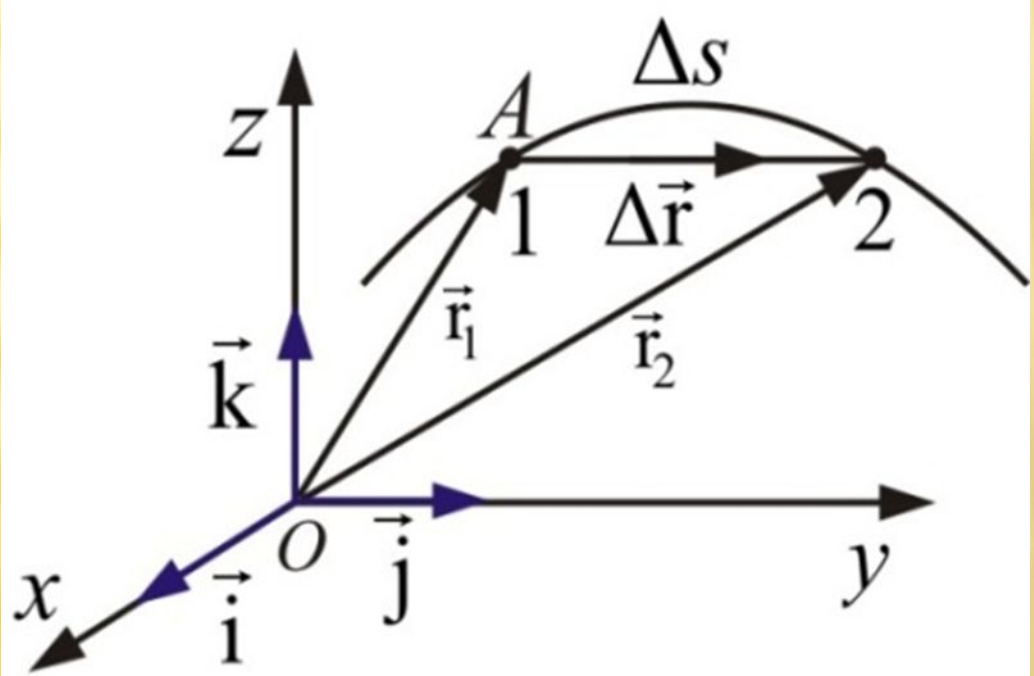
- Every motion is relative, so it is necessary to describe the motion conditions on any other body will be counted from the movement of the body. Selected for this purpose body called the body of the countdown.
- In practice, to describe the motion necessary to communicate with the body of the countdown coordinate system (Cartesian, spherical, cylindrical, etc.).

REFERENCE SYSTEM

- Reference system - a set of coordinates and hours related to the body with respect to which the motion is studied.
- Body movements, like matter, can not in general be out of time and space. Matter, space and time are inextricably linked to each other (no space without matter and time, and vice versa).

KINEMATICS OF A MATERIAL POINT

- The position of point A in the space can be defined by the radius vector drawn from the reference point O or the origin



DISPLACEMENT, PATH

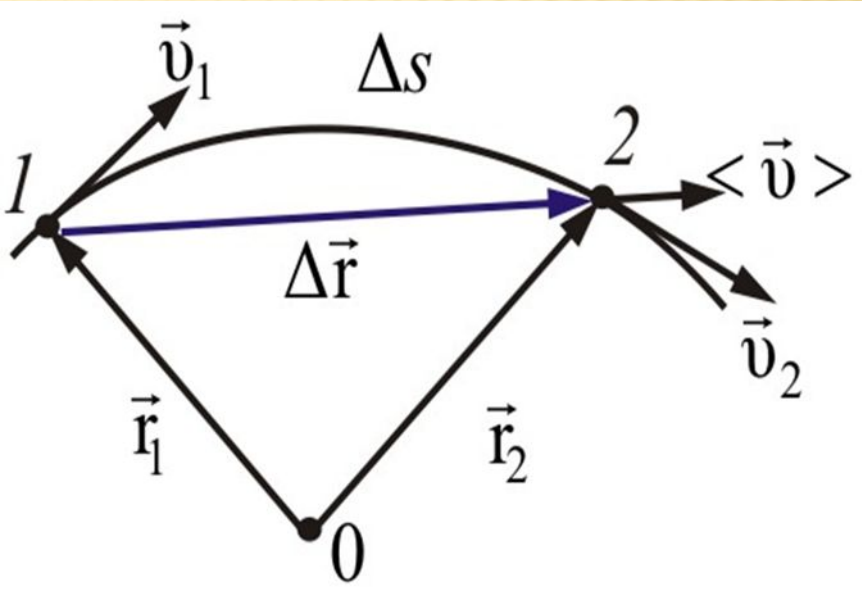
- When moving the point A from point 1 to point 2 of its radius vector changes in magnitude and direction, ie, It depends on the time t.
- The locus of all points is called a trajectory point.

- The length of the path is the path Δs. If the point moves in a straight line, then the increment is the path Δs.

VELOCITY

- The average velocity vector is defined as the ratio of the displacement vector by the time Δt, for that this movement happened

$$\frac{\Delta\vec{r}}{\Delta t} = <\vec{\upsilon}>$$



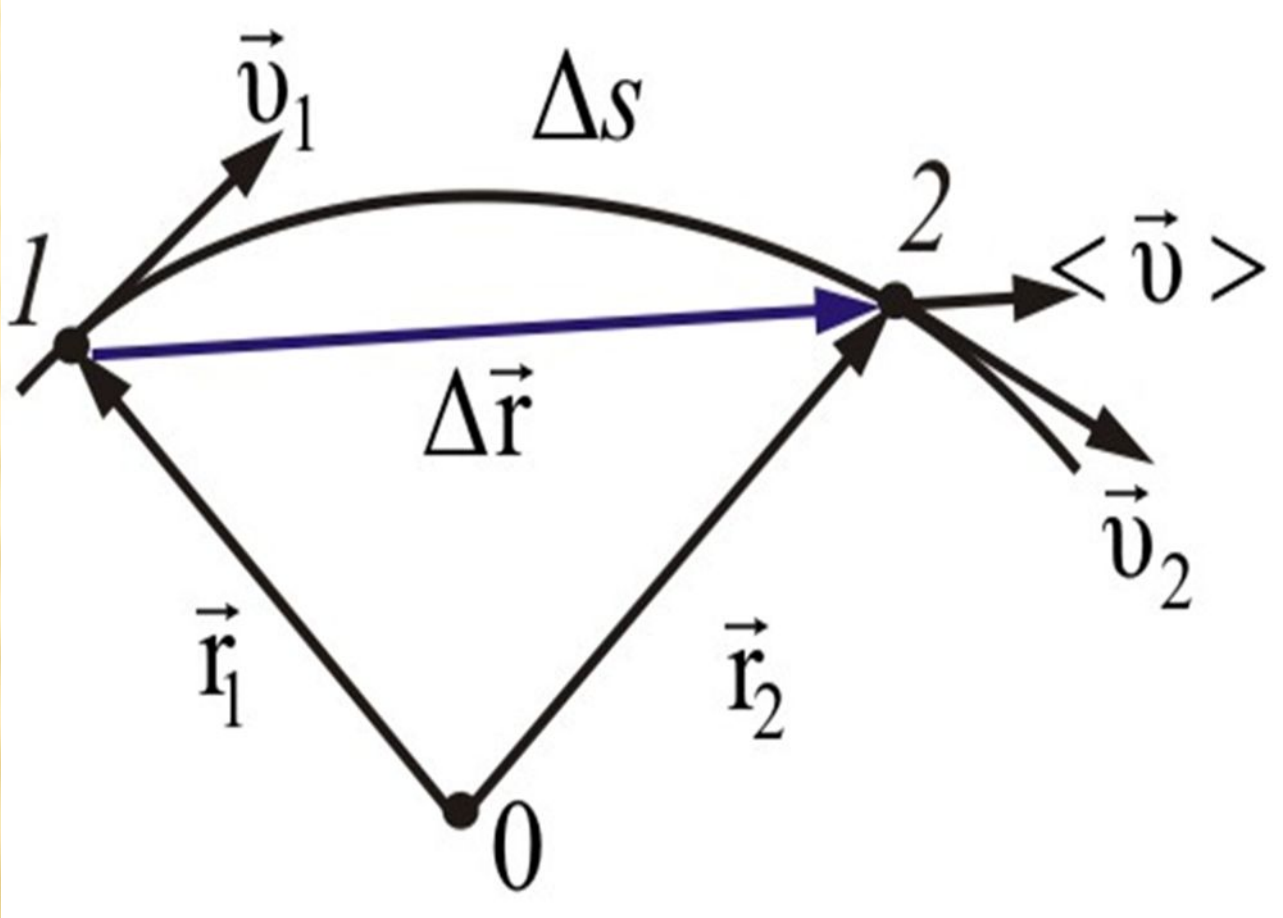
Vector coincides with direction of the vector $<\vec{\upsilon}>$

INSTANTANEOUS SPEED

- When Δt =0 Δ - an infinitely small part of trajectory
- ΔS = Δr movement coincides with the trajectory) In this case, the instantaneous velocity can be expressed by a scalar value - the path:

$$\upsilon = \lim_{\Delta t \to 0} \frac{\Delta s}{\Delta t} = \frac{\mathrm{d}s}{\mathrm{d}t}; \qquad \text{или} \qquad \upsilon = \frac{\mathrm{d}s}{\mathrm{d}t}.$$

INSTANTANEOUS SPEED



ACCELERATION. THE NORMAL AND TANGENTIAL ACCELERATION

- In the case of an arbitrary speed does not remain constant motion. The speed rate of change in magnitude and direction of acceleration are characterized

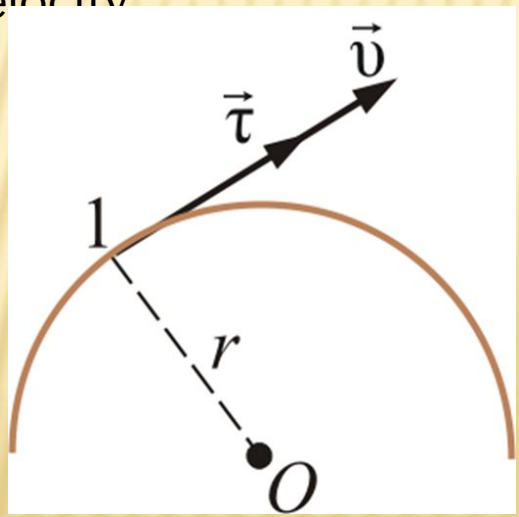
$$\vec{a} = \frac{\mathrm{d}\vec{\upsilon}}{\mathrm{d}t}$$

ACCELERATION

- We introduce the unit vector associated with point 1, and directed at a tangent to the trajectory of the point 1 (vectors and at 1 match).Then we can write:

$$\boxed{\vec{\upsilon} = \upsilon\vec{\tau},}$$

Where - the magnitude of the velocity



ACCELERATION

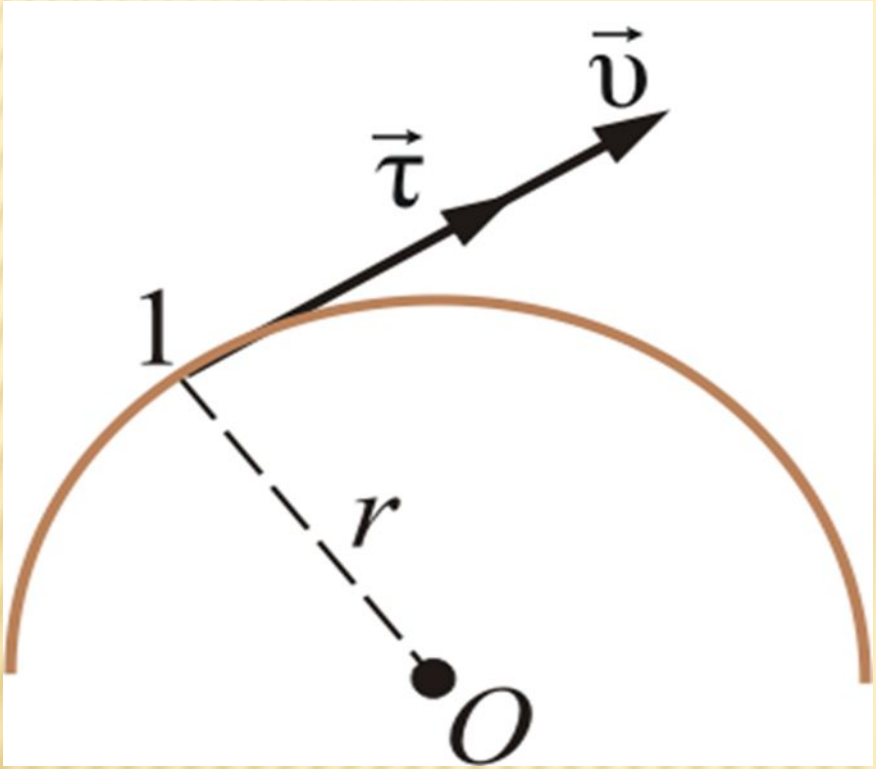
- We find the overall acceleration (a derivative)

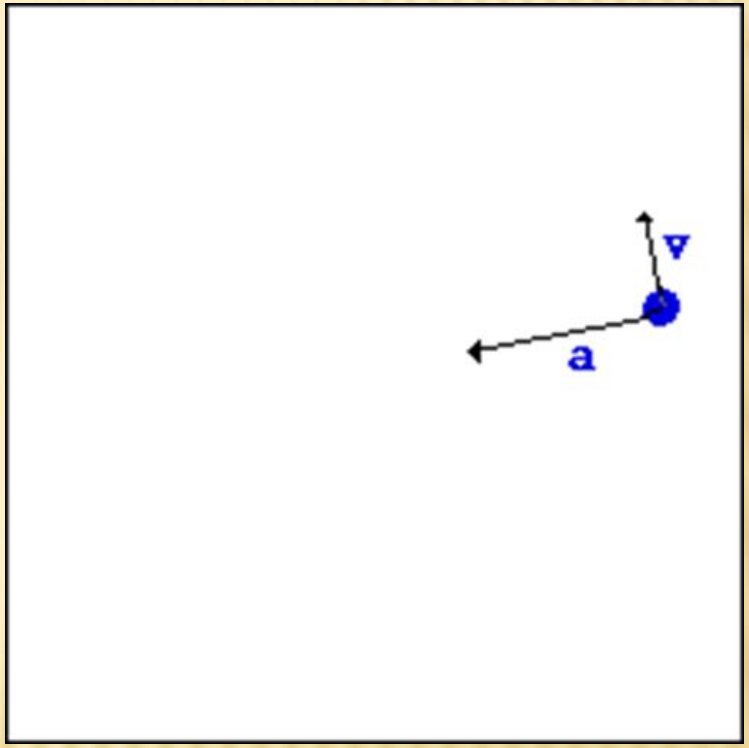
$$\boxed{\vec{a} = \frac{\mathrm{d}\vec{\upsilon}}{\mathrm{d}t} = \frac{\mathrm{d}\upsilon}{\mathrm{d}t}\vec{\tau} + \upsilon\frac{\mathrm{d}\vec{\tau}}{\mathrm{d}t} = \vec{a}_{\tau} + \vec{a}_{n}.}$$

$$\vec{a}_{\tau}$$

$$\vec{a}_{n}$$

TANGENTIAL AND NORMAL ACCELERATION





KINEMATICS OF ROTATIONAL MOTION

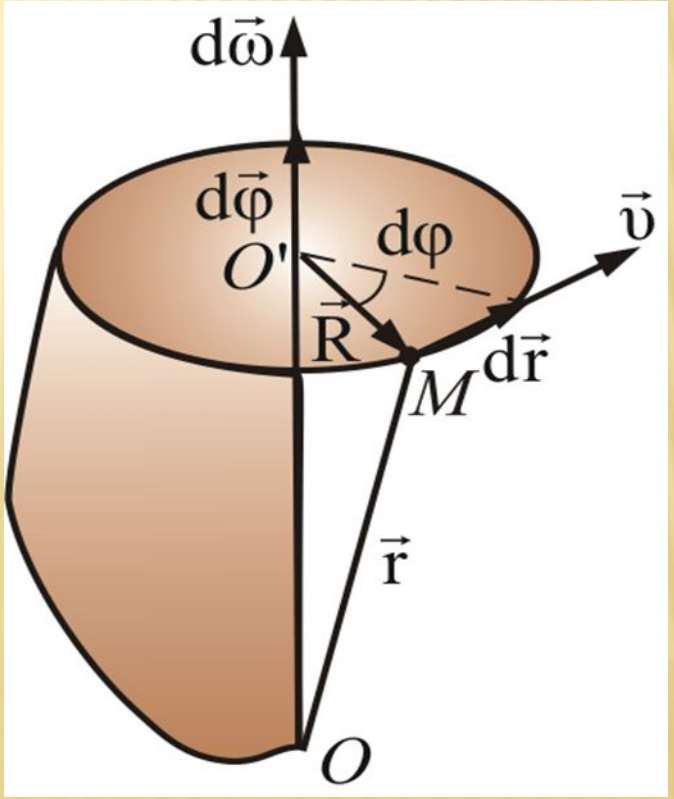
- The motion of a rigid body in which the two points O and O 'are fixed, called the rotational motion around a fixed axis, and the fixed line OO' is called the axis of rotation.

ANGULAR VELOCITY

- It is the vector angular velocity is numerically equal to the first derivative of the angle in time and directed along the rotation axis direction (and always in the same direction).

$$\vec{\omega} = \frac{d\vec{\varphi}}{dt}$$

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

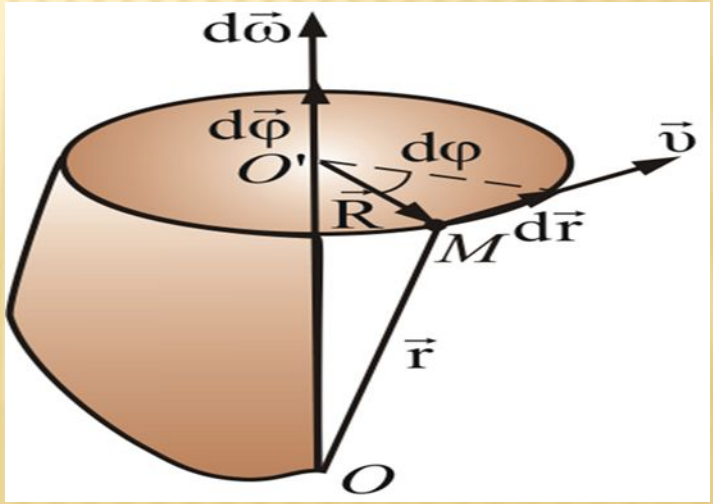


CONTACT THE LINEAR AND ANGULAR VELOCITY

- Let - linear velocity of the point M.
- During the time interval dt the point M passes the way at the same time $\mathrm{d}r = \upsilon \mathrm{d}t$.
- $\mathrm{d}r = R\mathrm{d}\varphi$ (Central angle). Then,

$$\boxed{\upsilon = \frac{\mathrm{d}r}{\mathrm{d}t} = \frac{R\mathrm{d}\varphi}{\mathrm{d}t} = \omega R}$$

$$\boxed{\upsilon = \omega R}$$



THE CONCEPTS OF ROTATIONAL MOTION

- Period T - period of time during which the body makes a complete revolution (turn on the corner)

$$T = \frac{2\pi}{\omega};$$

The frequency ν - number of revolutions of the body in 1 second

$$\nu = \frac{1}{T}.$$

$$\omega = \frac{2\pi}{T} = 2\pi\nu;$$

ANGULAR ACCELERATION

- We express the normal and tangential acceleration of M through the angular velocity and angular acceleration

$$a_\tau = \frac{d\upsilon}{dt} = \frac{d}{dt}(\omega R) = R\frac{d\omega}{dt} = R\varepsilon;$$

$$\boxed{a_\tau = R\varepsilon;}$$

$$\boxed{a_n = \frac{\upsilon^2}{R} = \omega^2 R.}$$

$$\boxed{a_n = \frac{\upsilon^2}{R} = \omega^2 R.}$$

$$\boxed{a_n = \frac{4\pi^2 R}{T^2} = 4\pi^2 \nu^2 R}$$

THE CONNECTION BETWEEN THE LINEAR AND ANGULAR VALUES THE ROTATIONAL MOVEMENT:

$$s = R\varphi$$

$$a = \sqrt{a_\tau^2 + a_n^2}$$

$$\upsilon = R\omega$$

$$a_\tau = R \cdot \varepsilon.$$

$$\vec{a} = \vec{a}_\tau + \vec{a}_n$$

$$a_n = \frac{4\pi^2 R}{T^2} = 4\pi^2 \nu^2 R$$

$$a_n = \upsilon^2 / R = \omega^2 R$$

THE CONNECTION BETWEEN THE LINEAR AND ANGULAR VALUES THE ROTATIONAL MOVEMENT:

Поступательное движение	Вращательное движение
$\upsilon = \frac{dS}{dt}$	$\omega = \frac{d\varphi}{dt}$
$a = \frac{d\upsilon}{dt}$	$\varepsilon = \frac{d\omega}{dt}$
$\upsilon = \upsilon_0 \pm at$	$\omega = \omega_0 \pm \varepsilon t$
$S = \upsilon_0 t \pm \frac{at^2}{2}$	$\varphi = \omega_0 t \pm \frac{\varepsilon t^2}{2}$
$S = \int_0^t \upsilon dt$	$\varphi = \int_0^t \omega dt$

DYNAMICS

- Dynamics (from the Greek dynamis - force) is studying the motion of bodies in connection with the reasons that cause this movement.

NEWTON'S FIRST LAW. INERTIAL SYSTEMS

- The so-called classical or Newtonian mechanics are three laws of dynamics, formulated by Newton in 1687. These laws play a crucial role in the mechanics and are (like all the laws of physics) a generalization of the results of vast human experience.

NEWTON'S FIRST LAW

- Every material point stores the state of rest or uniform rectilinear motion until such time as the effects of other bodies will not force her to change this state.

$$\vec{F} = 0, \ \upsilon = \text{const} \text{ или } 0$$

NEWTON'S FIRST LAW

- Both of these states are similar in that the acceleration body is zero. Therefore, the first law of the formulation can be given as follows: speed of any body remains constant (in particular, zero), while the impact on the body by other bodies it will not cause change.

NEWTON'S FIRST LAW

- The desire to preserve the body state of rest or uniform rectilinear motion is called inertia. Therefore, Newton's first law is called the law of inertia.

INERTIA

- Inertial frame of reference is such a frame of reference with respect to which a material point, free from external influences, either at rest or moving uniformly (ie, at a constant speed).

- Thus, Newton's first law asserts the existence of inertial reference systems.

THE MASS AND MOMENTUM OF THE BODY

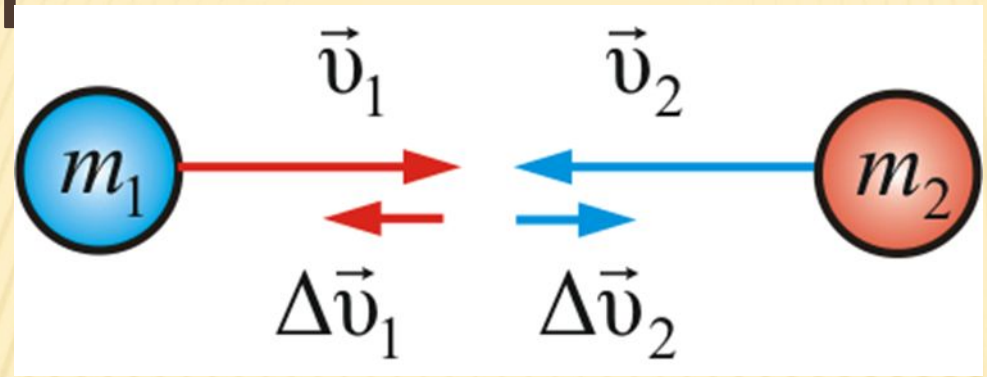
- Exposure to this body by other bodies causes a change in its speed, i.e. according to this body acceleration.
- Experience shows that the same effect according to different bodies of different sizes acceleration. Every body resists attempts to change its state of motion. This property of bodies, as we have said, is called inertia (this follows from Newton's first law).
- The measure of inertia of a body is a quantity called the mass.
- To determine the mass of a body, you need to compare it with the weight taken as the standard body weight (or compare it with already known body mass).

THE MASS AND MOMENTUM OF THE BODY

- Mass - the value of the additive (body weight equal to the sum of the masses of parts that make up this body).
- Systems, interacting only with each other, said to be closed.
- Consider a closed system of two bodies of masses and be faced these two bodies

m_1 m_2

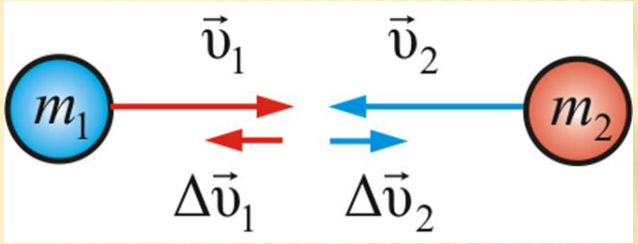
THE MASS AND MOMENTUM OF THE BODY



Experience shows that the speeds have the opposite directions which are different in sign but equal in absolute value

THE MASS AND MOMENTUM OF THE BODY

$$\frac{|\Delta\vec{\upsilon}_1|}{|\Delta\vec{\upsilon}_2|} = \frac{m_2}{m_1}$$



Taking into account the direction of the velocity, we can write:

$$m_1\Delta\vec{\upsilon}_1 = -m_2\Delta\vec{\upsilon}_2.$$

$$\upsilon << c \qquad m = \text{const}$$

$$\Delta(m_1\vec{\upsilon}_1) = -\Delta(m_2\vec{\upsilon}_2).$$

MOMENTUM OF THE BODY

$$\boxed{\vec{\mathrm{p}} = m\vec{\upsilon}.}$$

NEWTON'S SECOND LAW

$$\boxed{\frac{d\vec{p}}{dt} = \vec{F}}$$

the rate of change of momentum of a body is equal to the force acting on it.

$$d\vec{p} = \vec{F}dt$$

From this we can conclude that the change of the momentum of a body is equal to the momentum forces.

$$\frac{d(m\vec{\upsilon})}{dt} = \vec{F}. \qquad m = \text{const} \qquad m\frac{d\vec{\upsilon}}{dt} = \vec{F}.$$

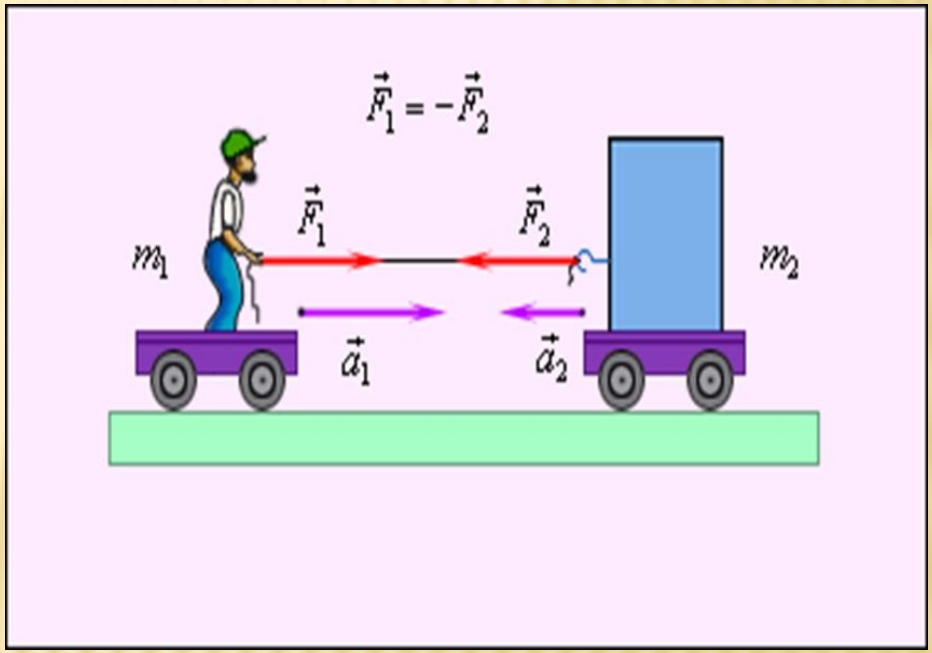
$$\frac{d\vec{\upsilon}}{dt} = \vec{a},$$

$$m\vec{a} = \vec{F}$$

NEWTON'S THIRD LAW

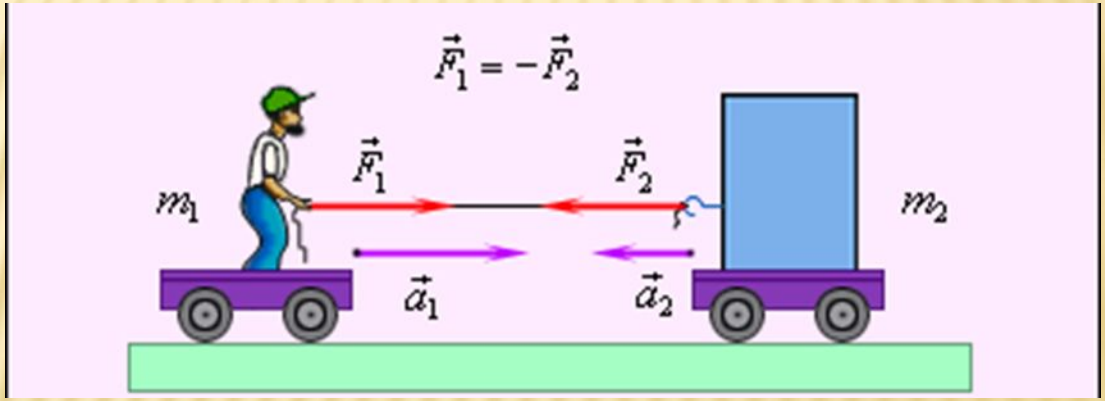
- Interacting bodies act on each other with the same magnitude but opposite in direction forces:

$$\vec{F}_{12} = -\vec{F}_{21}$$



EVERY ACTION CAUSES AN EQUAL LARGEST OPPOSITION

$$\vec{F}_{12} = -\vec{F}_{21}$$



THE LAW OF CONSERVATION OF MOMENTUM

- The mechanical system is called a closed (or isolated), if it is not acted upon by external forces, ie, it does not interact with external bodies.
- Strictly speaking, each real system of bodies is never closed because subject to a minimum the effects of gravitational forces. However, if the internal forces is much more external, that such a system can be considered closed (for example - the solar system).
- For a closed system resultant vector of the external forces it is identically equal to zero:
-

$$\frac{d\vec{p}}{dt} = \vec{F} \equiv 0,$$

THE LAW OF CONSERVATION OF MOMENTUM

$$\vec{\mathrm{p}} = \sum_{i=1}^{n} m_i \vec{\upsilon}_c = \mathrm{const.}$$

$$m\vec{\upsilon}_c = \mathrm{const.}$$

In all the processes occurring in closed systems, the speed of the center of mass remains unchanged.
The law of conservation of momentum is one of the fundamental laws of nature.
He was received as a consequence of Newton's laws, but it is also valid for the microparticles and to relativistic speeds

GRAVITY AND THE WEIGHT

- One of the fundamental forces - gravity force is manifested on Earth in the form of gravitational force - the force with which all bodies are attracted to the Earth.
- Near the Earth's surface all bodies fall with the same acceleration - the acceleration of gravity g, (remember school experience - "Newton's tube"). It follows that in the frame of reference associated with the earth, to every body the force of gravity $m\vec{g}$

acceleration of gravity

gravity

GRAVITY AND THE WEIGHT

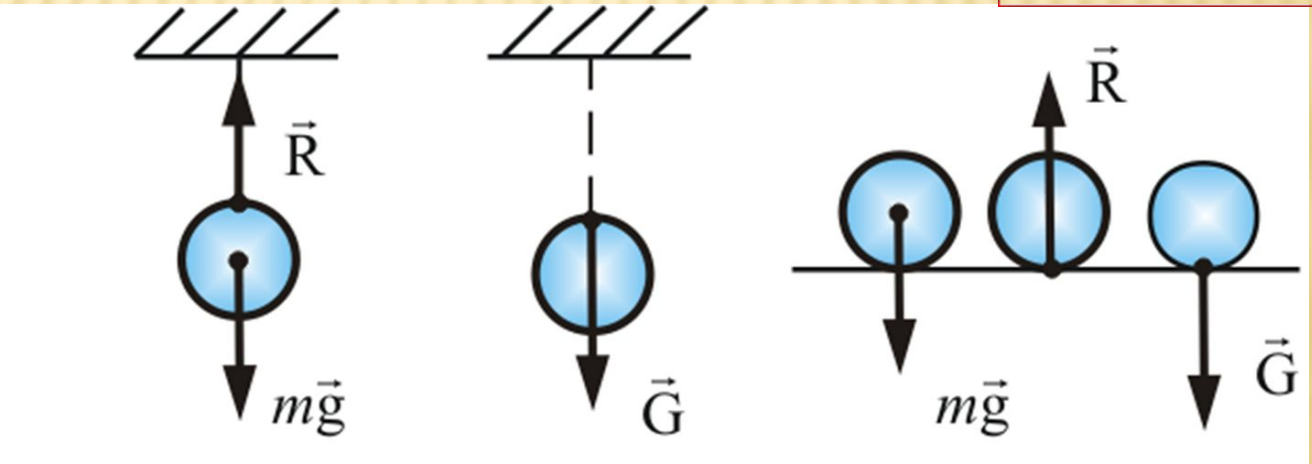
- If the body is hung or put it on a support, the force of gravity is balanced by the force, which is called the reaction support or suspension

$\vec{P} = -\vec{R}.$

$\vec{R}$ или $\vec{N}$

$m\vec{g} = -\vec{R}.$

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



FRICTIONAL FORCES

- Friction is divided into external and internal.
- External friction occurs when the relative movement of the two contacting solids (sliding friction or static friction).
- Internal friction occurs upon relative movement of parts of one and the same solid body (e.g., liquid or gas).

FRICTIONAL FORCES

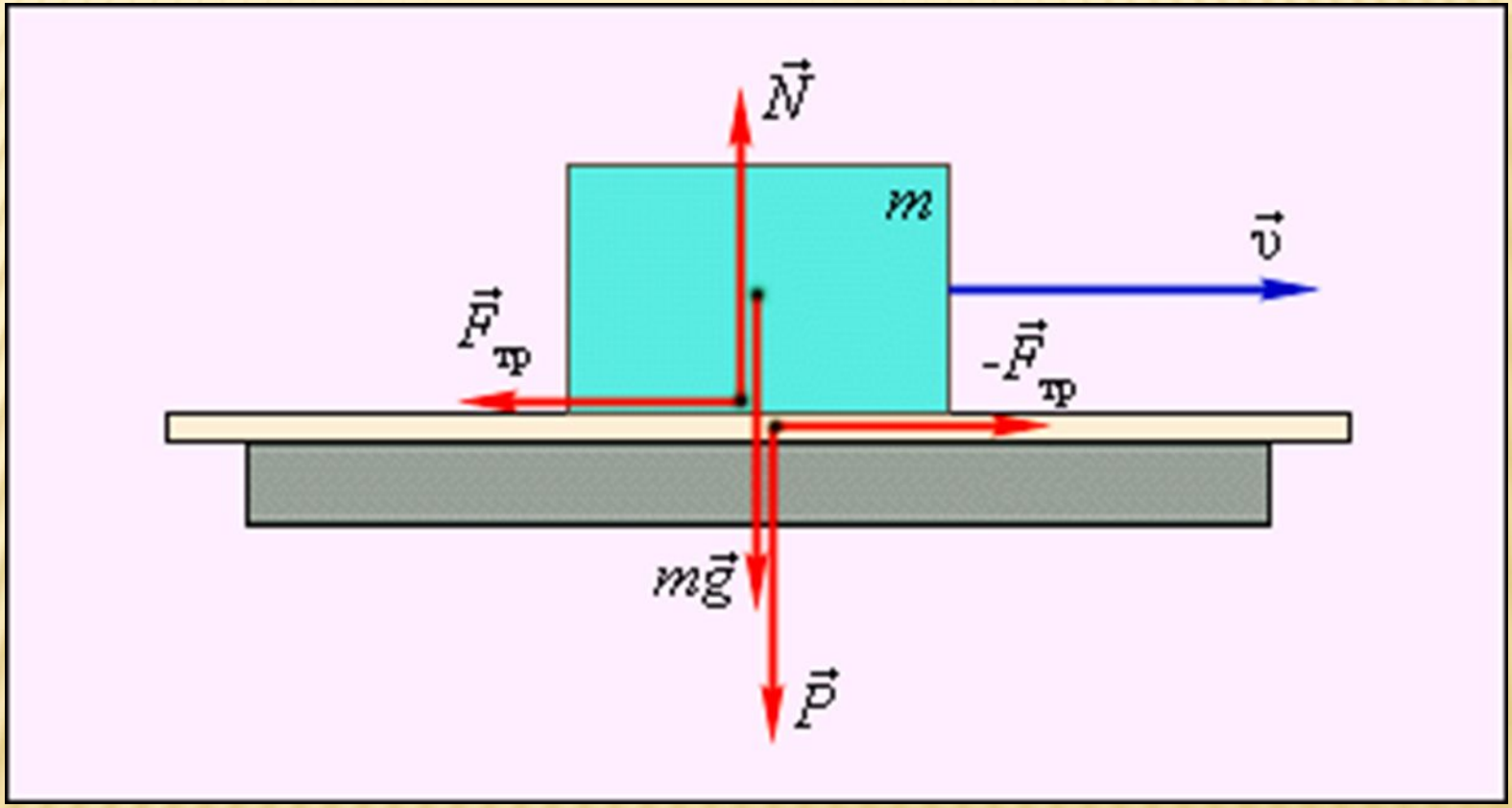
- Frictional forces - tangential forces arising in the contact surfaces of bodies and prevent their relative movement

$$F_{mp} = \mu N$$

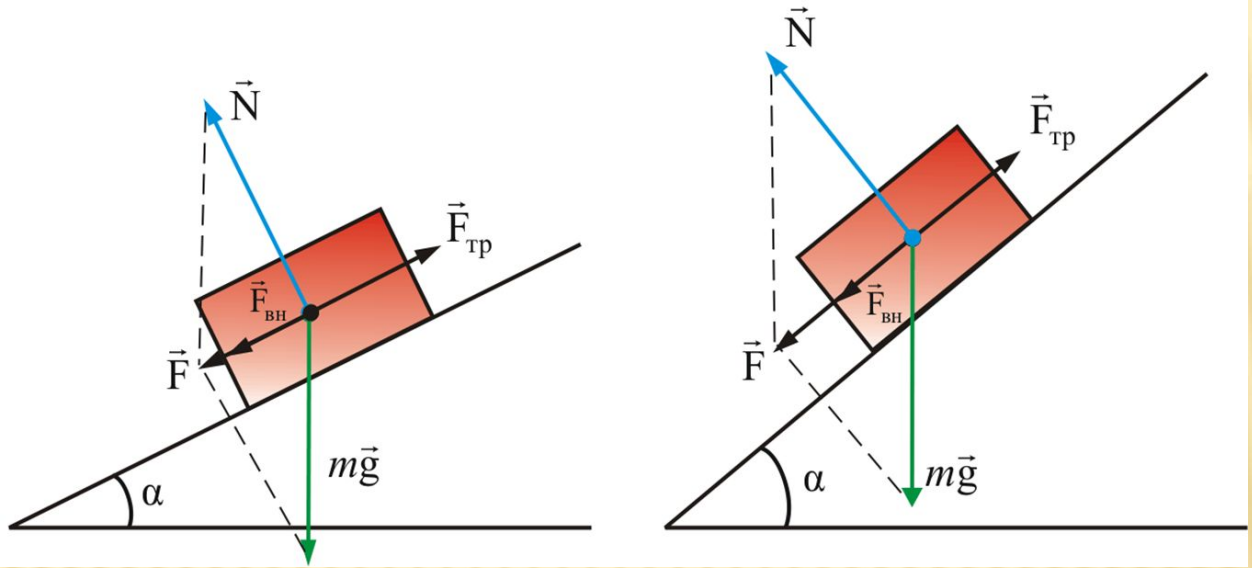
$$F_{mp} = \mu mg$$

friction coefficient

FRICTIONAL FORCES



INCLINED PLANE



$$F_{тр.} = \mu N = \mu mg\cos\alpha,$$

ENERGY. WORK. CONSERVATION LAWS

POTENTIAL ENERGY

- If the system of material bodies are conservative forces, it is possible to introduce the concept of potential energy.
- Work done by conservative forces when changing the system configuration, that is, when the position of the bodies relative to the frame, regardless of whether this change was implemented

THE FORMULA FOR THE POTENTIAL ENERGY

$$\boxed{U = mgh.}$$

KINETIC ENERGY

- The function of the system status, which is determined only by the speed of its motion is called kinetic energy.

$$K = \frac{m\upsilon^2}{2}.$$

The kinetic energy of the system is a function of the state of motion of the system.

UNITS OF ENERGY MEASUREMENT

- Energy is measured in SI units in the force works on the distance in newtons per meter (joules)

CONTACT OF THE KINETIC ENERGY WITH MOMENTUM P.

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

CONTACT OF THE KINETIC ENERGY WITH THE WORK.

- If a constant force acts on the body, it will move in the direction of the force. Then, the unit operation of the body movement of v. 1 to Vol. 2, is the product of force F to displacement dr

$$\mathrm{d}A = F\mathrm{d}r$$

CONTACT OF THE KINETIC ENERGY WITH THE WORK.

- Consequently, the work of the force applied to the body in the path r is numerically equal to the change in kinetic energy of the body:

$$A = \Delta K.$$

$$\mathrm{d}K = \mathrm{d}A.$$

kinetic energy is equal to the variation dK
of external forces:

Work, as well as the kinetic energy is
measured in joules.

POWER

- The rate of doing work (energy transfer) is called power.
- Power has the work done per unit of time.
- instantaneous power $$N = \frac{\mathrm{d}A}{\mathrm{d}t}$$

average power $$< N >= \frac{A}{\Delta t}.$$

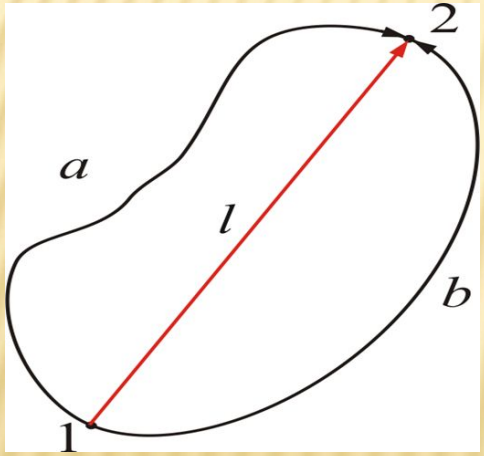
Power Unit -Vatt

CONSERVATIVE AND NON-CONSERVATIVE FORCES

- Also contact interactions observed interaction between bodies, distant from each other. This interaction takes place through physical fields (a special form of matter).
- Each body creates around itself a field, which manifests itself is the impact on other bodies.

CONSERVATIVE AND NON-CONSERVATIVE FORCES

- Force, whose work does not depend on the way in which the moving body, and depends on the initial and final position of the body are called conservative.



$$A_{1a2} = A_{1b2} = A_{1l2} = A_{12}.$$

CONSERVATIVE AND NON-CONSERVATIVE FORCES

- Conservative forces: gravity, electrostatic forces, the forces of the central stationary field.
- Non-conservative forces: the force of friction, the forces of the vortex electric field.
- Conservative system - such inner strength that only conservative external - conservative and stationary.

THE RELATIONSHIP BETWEEN POTENTIAL ENERGY AND FORCE

- The space in which there are conservative forces, called the potential field.
- Each point corresponds to a potential field strength value
- acting on the body, and a value of the potential energy U.

$$\vec{F} = -\frac{dU}{d\vec{r}}.$$

THE LAW OF CONSERVATION OF MECHANICAL ENERGY

- The law of conservation brings together the results we obtained earlier.
- In the forties of the nineteenth century works of R. Mayer, Helmholtz and John. Joule (all at different times and independently of each other) has been proved by the law of conservation and transformation of energy.

THE LAW OF CONSERVATION OF MECHANICAL ENERGY

- For a conservative system of particles the total energy of the system:

$$E = K + U_{\text{внутр.}} + U_{\text{внеш.}} = \text{const}$$

For the law of conservation of mechanical energy is: total mechanical energy-Conservatory-conservative system of material points remains constant.

FOR A CLOSED SYSTEM

$$E = K + U_{\text{внутр.}} = \text{const}$$

the total mechanical energy of a closed system of material points between which there are only conservative forces, remains constant.

COLLISIONS

ABSOLUTELY ELASTIC CENTRAL COLLISION

- With absolutely elastic collision - this is a blow, in which there is no conversion of mechanical energy into other forms of energy.

$$\upsilon'_1 = \frac{2m_2\upsilon_2 + (m_1 - m_2)\upsilon_1}{m_1 + m_2};$$

$$\upsilon'_2 = \frac{2m_1\upsilon_1 + (m_2 - m_1)\upsilon_2}{m_1 + m_2}$$

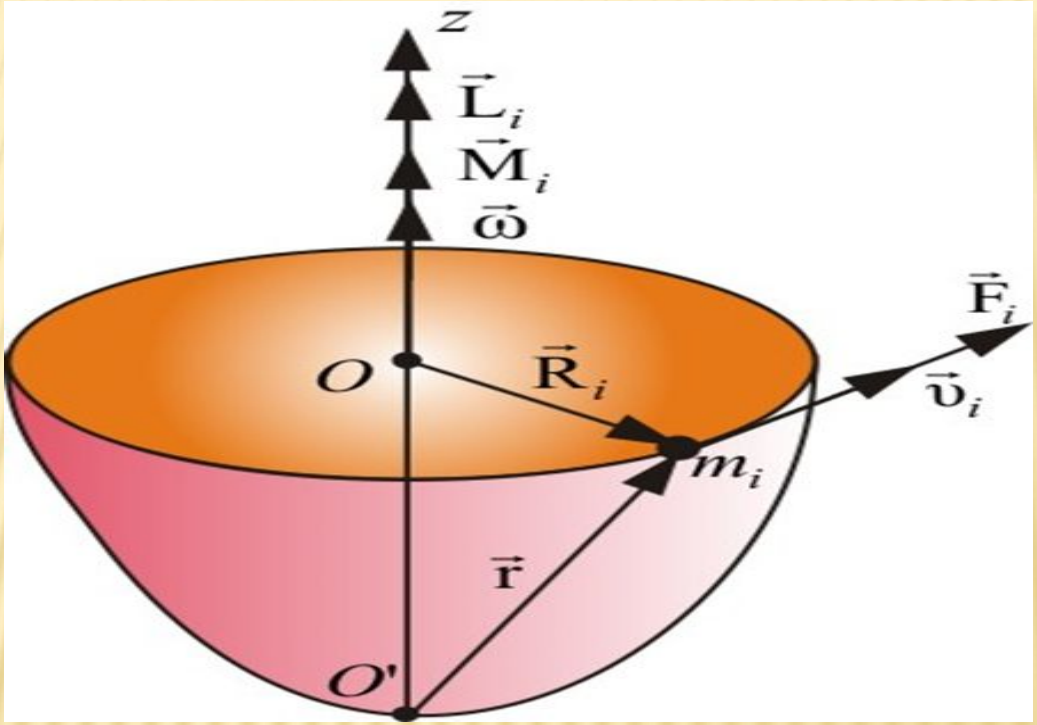
INELASTIC COLLISION

- Inelastic collision - a collision of two bodies, in which the body together and move forward as one.

$$\upsilon = \frac{m_1\upsilon_1 + m_2\upsilon_2}{m_1 + m_2}.$$

DYNAMICS OF ROTATIONAL MOTION OF THE SOLID BODY

DYNAMICS OF ROTATIONAL MOTION OF A SOLID BODY RELATIVED TO THE AXIS



MOMENT OF INERTIA

$$I = \int_0^m R^2 \mathrm{d}m,$$

THE MAIN BODY DYNAMICS EQUATION OF ROTATING AROUND A FIXED AXIS

$$I\vec{\varepsilon} = \vec{M}$$

AUXILIARY EQUATIONS

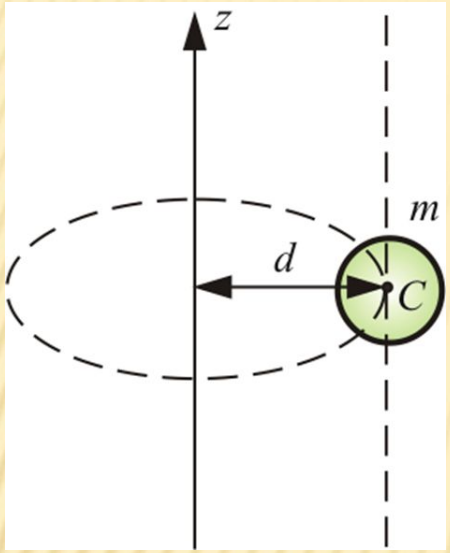
$$I\frac{\mathrm{d}\vec{\omega}}{\mathrm{d}t} = \vec{\mathrm{M}}$$

$$I\mathrm{d}\vec{\omega} = \vec{\mathrm{M}}\mathrm{d}t;$$

$$I\mathrm{d}\vec{\omega} = \mathrm{d}\vec{\mathrm{L}}$$

$$\vec{\mathrm{L}} = I\vec{\omega}$$

STEINER'S THEOREM



$$I = I_c + md^2$$

Moment of inertia I with respect to any axis of rotation is equal to the time of his inertia I_c

relative to the parallel axis passing through the mass center C of body weight plus the product of square of the distance between the axles.

THE KINETIC ENERGY OF A ROTATING BODY

- The kinetic energy - the value of the additive, so that the kinetic energy of a body moving in an arbitrary manner, is the sum of the kinetic energies of all n material points by which this body can mentally break:

$$K = \sum_{i=1}^{n} \frac{m_i \upsilon_i^2}{2}.$$

TRANSLATION AND ROTATIONAL MOTION

- The total kinetic energy of the body:

$$K_{\text{полн.}} = \frac{m\upsilon_c^2}{2} + \frac{I_c\omega^2}{2}$$

RELATIVISTIC MECHANICS

GALILEO'S PRINCIPLE OF RELATIVITY.

- In describing the mechanics was assumed that all the velocity of the body is much less than the speed of light. The reason for this is that Newton's mechanics (classical) is incorrect, at speeds of bodies close to the speed of light

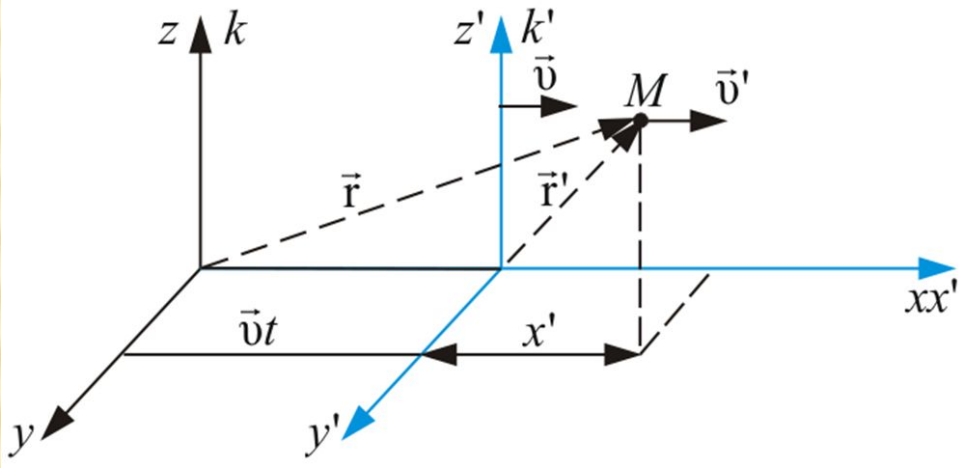
$$(\upsilon \to c)$$

The correct theory for this case is called relativistic mechanics or the special theory of relativity

GALILEAN TRANSFORMATION

- According to classical mechanics: mechanical phenomena occur equally in the two reference frames moving uniformly in a straight line relative to each other.

GALILEAN TRANSFORMATION



$$\left.\begin{aligned} x &= x' + \upsilon t \\ y &= y' \\ z &= z' \\ t &= t' \end{aligned}\right\}$$

$$\vec{r} = \vec{r}' + \vec{\upsilon} t.$$

INTERVAL OF THE SPACE

$$\Delta l_{12} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} =$$

$$= \sqrt{(x'_1 - x'_2)^2 + (y'_1 - y'_2)^2 + (z'_1 - z'_2)^2} =$$

$$= \Delta l'_{12} = inv$$

GALILEAN TRANSFORMATION

- Moments of time in different reference frames coincide up to a constant value determined by the procedure of clock synchronization $t = t' + const$

$$\boxed{\vec{a} = \vec{a}_0 + \vec{a}'}$$

$$\boxed{\vec{r} = \vec{r}_0 + \vec{r}'}$$

$$\boxed{t = t'}$$

$$\boxed{\vec{\mathrm{v}} = \vec{\mathrm{v}}_0 + \vec{\mathrm{v}}'}$$

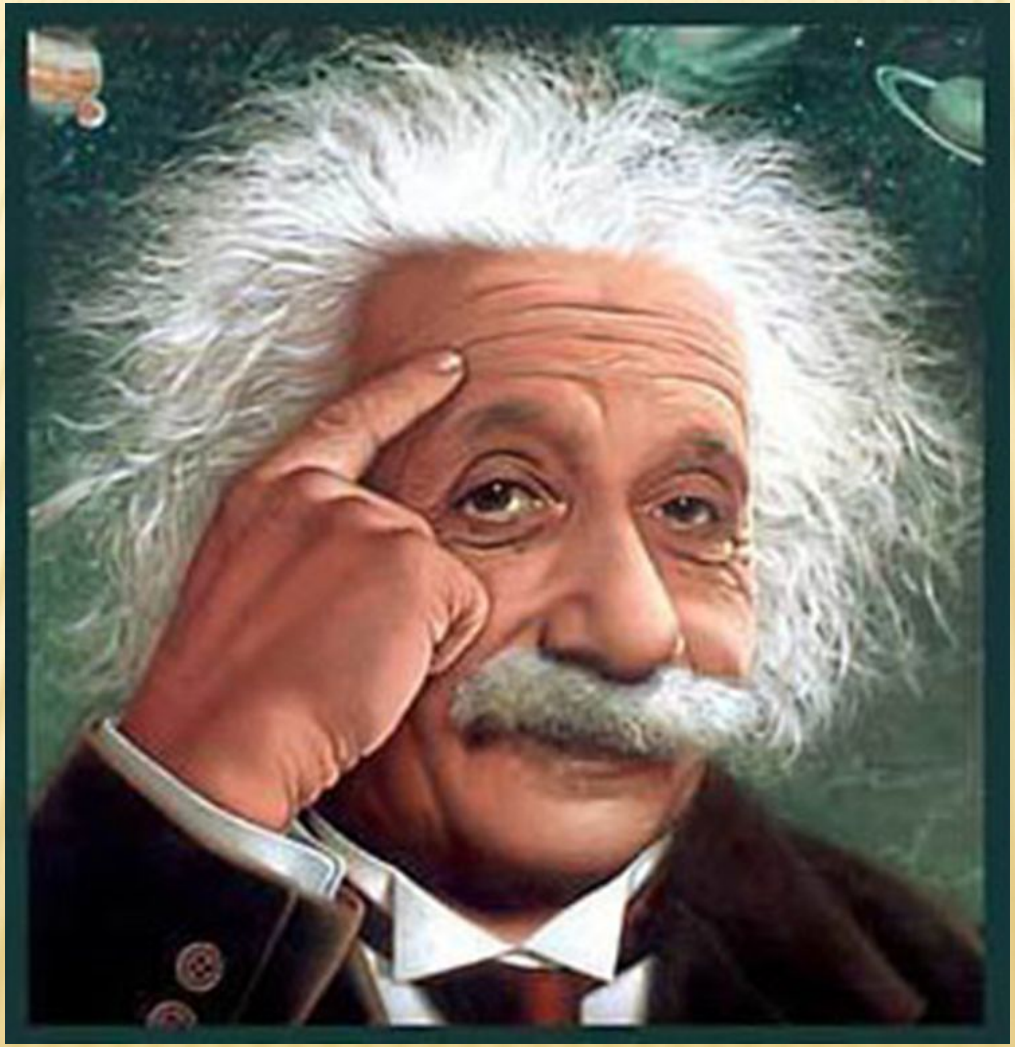
GALILEO'S PRINCIPLE OF RELATIVITY.

- The laws of nature that determine the change in the state of motion of mechanical systems do not depend on which of the two inertial reference systems they belong

EINSTEIN'S PRINCIPLE OF RELATIVITY

- In 1905 in the journal "Annals of Physics" was published a famous article by A. Einstein "On the Electrodynamics of Moving Bodies", in which the special theory of relativity (SRT) was presented.
- Then there was a lot of articles and books explaining, clarifying, interpreting this theory.

TWO OF EINSTEIN'S POSTULATE



TWO OF EINSTEIN'S POSTULATE

- 1. All laws of nature are the same in all inertial reference systems.
- 2. The speed of light in a vacuum is the same in all inertial reference systems, and does not depend on the velocity of the source and the light receiver.

$$c = \text{const}$$

LORENTZ TRANSFORMATIONS

- Formula conversion in the transition from one inertial system to another, taking into account Einstein's postulates suggested Lorenz in 1904

LORENTZ TRANSFORMATIONS

- Lorenz established a link between the coordinates and time of the event in the frame k and k 'based on the postulates of SRT
- Thus, at high speeds comparable to the speed of light received Lorenz

LORENTZ TRANSFORMATIONS

$$x = \frac{x' + \upsilon t}{\sqrt{1 - \beta^2}}$$

$$y = y'$$

$$z = z'$$

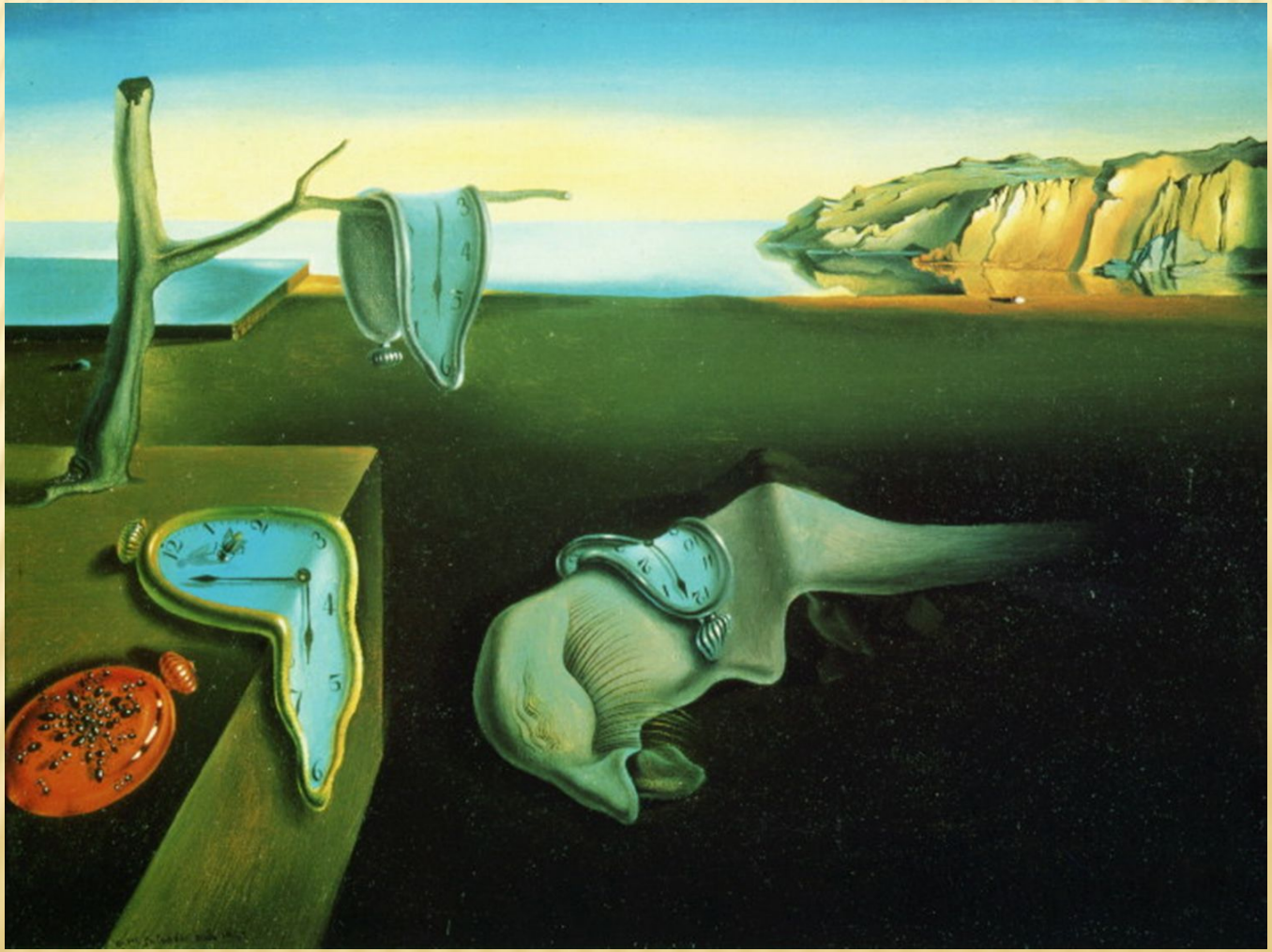
$$t = \frac{t' + \frac{\upsilon x'}{c^2}}{\sqrt{1 - \beta^2}}$$

$$\beta = \frac{\upsilon}{c}$$

FOURTH DIMENSION

- The true physical meaning of Lorentz transformations was first established in 1905 by Einstein in SRT. In the theory of relativity, time is sometimes called the fourth dimension. More precisely, ct value of having the same dimension as x, y, z behaves as a fourth spatial coordinate. In the theory of relativity ct and x manifest themselves from a mathematical point of view in a similar way.

FOURTH DIMENSION



FOURTH DIMENSION

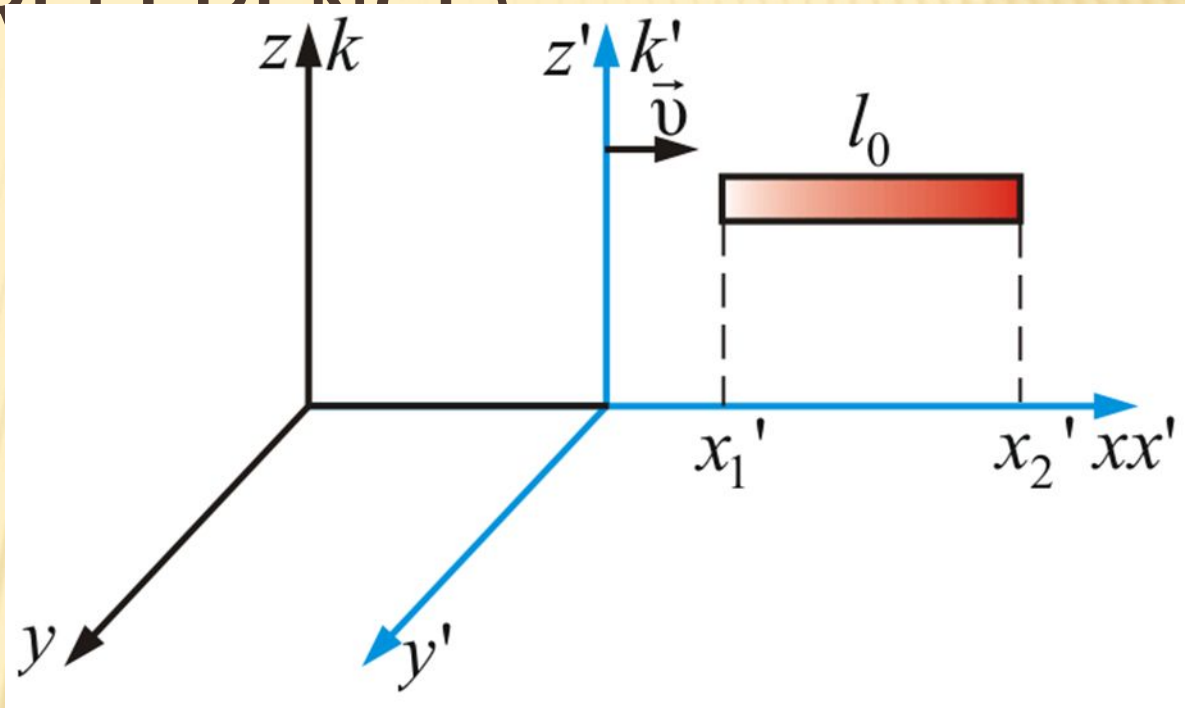
- At low speeds or, at infinite speed bye-injury theory of long-range interactions), the Lorentz transformations turn into Galileo's transformation (matching principle).

CONCLUSIONS OF THE LORENTZ TRANSFORMATIONS

- 1)Lorentz transformations demonstrate the inextricable link spatial and temporal properties of our world (the world of four-dimensional).
- 2)On the basis of the Lorentz transformation can be described by the relativity of simultaneity.
- 3) It is necessary to introduce a relativistic velocity addition law.

LORENTZ CONTRACTION LENGTH (LENGTH OF BODIES IN DIFFERENT FRAMES OF REFERENCE)

$$l_0 = \frac{l}{\sqrt{1-\beta^2}};$$

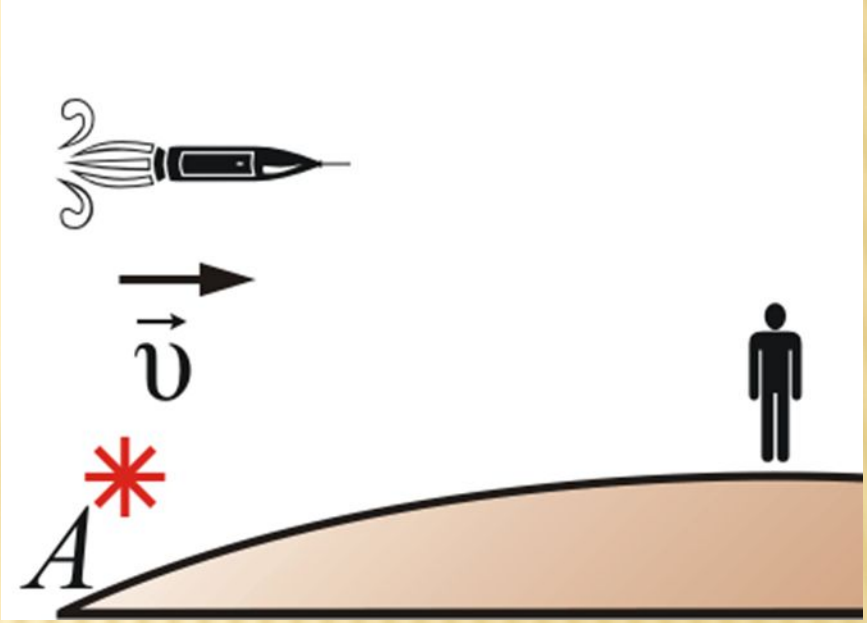


$$\text{или} \quad l = l_0\sqrt{1-\beta^2}$$

moving body length shorter than the resting

SLOWING DOWN TIME (DURATION OF THE EVENT IN DIFFERENT FRAMES OF REFERENCE)

$$\Delta t = \frac{\tau}{\sqrt{1-\beta^2}}$$



The proper time - lowest (moving clocks run slower resting)

MASS, MOMENTUM AND ENERGY IN RELATIVISTIC MECHANICS

THE RELATIVISTIC INCREASE IN MASS OF THE PARTICLES OF MATTER

$$m = \frac{m_0}{\sqrt{1 - \frac{\upsilon^2}{c^2}}}$$

THE RELATIVISTIC EXPRESSION FOR MOMENTUM

$$\vec{p} = \frac{m\vec{\upsilon}}{\sqrt{1-\beta^2}}$$

THE RELATIVISTIC EXPRESSION FOR THE ENERGY

$$E = \frac{mc^2}{\sqrt{1-\beta^2}}$$

$$\upsilon = 0$$

$$E_0 = mc^2$$

MOLECULAR-KINETIC THEORY

THE EFFECT OF STEAM

- Jet Propulsion ball mounted on a tubular racks, by the reaction provided by the escaping steam, it has been demonstrated 2000 years ago Hero of Alexandria.

BASIC CONCEPTS AND DEFINITIONS OF MOLECULAR PHYSICS AND THERMODYNAMICS

- The set of bodies making up the macroscopic system is called thermodynamic system.
- The system can be in different states. The quantities characterizing the system status, condition called parameters: pressure P, T the temperature, the volume V, and so on. Communication between the P, T, V is specific for each body is called an equation of state.

BASIC CONCEPTS AND DEFINITIONS OF MOLECULAR PHYSICS AND THERMODYNAMICS

- Any parameter having a certain value for each of the equilibrium state is a function of the system state. The equilibrium system - such a system, the state parameters which are the same in all points of the system and does not change with time (at constant external conditions). Thus in equilibrium are selected macroscopic portion of the system.

BASIC CONCEPTS AND DEFINITIONS OF MOLECULAR PHYSICS AND THERMODYNAMICS

- The process - the transition from one equilibrium state to another. Relaxation - the return of the system to an equilibrium state. Transit Time - the relaxation time

THE ATOMIC WEIGHT OF CHEMICAL ELEMENTS (ATOMIC WEIGHT) A

$$A = \frac{m_A(\text{масса атома элемента})}{m_{\text{ед}}(1/12 \text{ массы атома углерода})}.$$

THE MOLECULAR WEIGHT (MW)

$$M = \frac{m_M\,(\text{масса молекулы})}{m_{\text{ед}}}.$$

From here you can find a lot of atoms and molecules in kilograms:

$$m_A = A m_{\text{ед}}$$

$$m_M = M m_{\text{ед}}$$

DEFINITIONS

- In thermodynamics, the widely used concept of k-mol, mole, Avogadro's number and the number of Loschmidt.

  We give a definition of these quantities.
- Mol - a standardized amount of any substance in gaseous, liquid or solid state. 1 mol - the number of grams of material equal to its molecular weight.

NUMBER OF AVOGADRO

- In 1811 Avogadro suggested that the number of particles per kmol of any substance is constant and equal to the called, in consequence, the number of Avogadro

$$N_A = 6{,}022 \cdot 10^{23} \frac{1}{\text{моль}}.$$

Molar mass - the mass of one mole of
(μ)

$$\mu = A m_{\text{ед}} N_A.$$

NUMBER OF LOSCHMIDT

- At the same temperatures and pressures of all the gases contained in a unit volume of the same number of molecules. The number of ideal gas molecules contained in 1 m3 under normal conditions, is called the number Loschmidt:

$$N_L = P_0 / kT_0 = 2{,}68 \cdot 10^{25} \text{ м}^{-3}$$

k = 1,38 · 10(-23) J / K - Boltzmann constant

PRESSURE. THE BASIC EQUATION OF MOLECULAR-KINETIC THEORY

- gas pressure - there
- consequence of the collision gas
- molecules with the walls of the vessel.

PRESSURE

или $$P = \frac{1}{3} m_0 \upsilon_x^2$$

THE BASIC EQUATION OF MOLECULAR-KINETIC THEORY OF GASES.

$$P = \frac{2}{3} n < E_k >$$

Gas pressure is determined by the average kinetic energy of the translational motion of the molecules.

TEMPERATURE

$$T = \frac{2}{3k}\frac{m_0 < \upsilon^2 >}{2}$$

$$\frac{m_0 < \upsilon^2 >}{2} = \frac{3}{2}kT.$$

$$R = kN_A,$$

R - universal gas constant

$$R = 8{,}31\frac{\text{Дж}}{\text{моль}\cdot\text{К}} = 8{,}31\cdot 10^3\frac{\text{Дж}}{\text{кмоль}\cdot\text{К}}$$

THE BASIC EQUATION OF MOLECULAR-KINETIC THEORY-2

$$P = nkT$$

THE PROBABILITY OF THE EVENT. THE CONCEPT OF THE DISTRIBUTION OF THE VELOCITY OF THE GAS MOLECULES

- From the standpoint of atomic-molecular structure of the substance values found in macroscopic physics, the sense of average values, which take some of the features from microscopic variables of the system. Values of this kind are called statistics. Examples of such variables are pressure, temperature, density and others.

THE PROBABILITY OF THE EVENT. THE CONCEPT OF THE DISTRIBUTION OF THE VELOCITY OF THE GAS MOLECULES

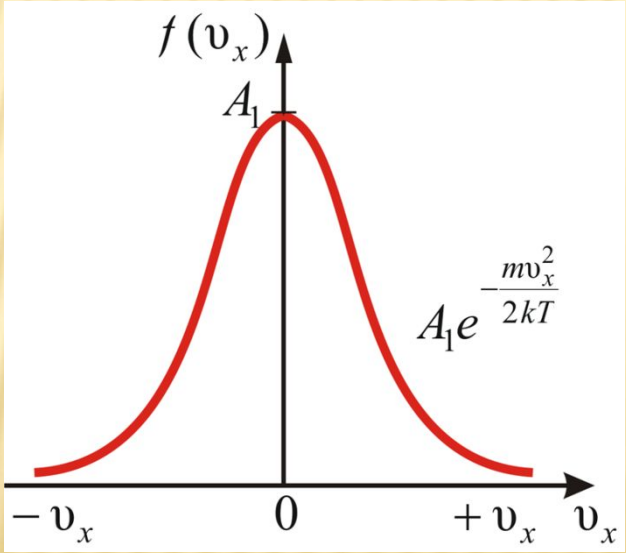
- A large number of colliding atoms and molecules causes important patterns in the behavior of statistical variables, not peculiar to individual atoms and molecules. ? These patterns are called probabilistic or statistical

MAXWELL DISTRIBUTION FUNCTION

- Suppose there are n identical molecules in a state of random thermal motion at a certain temperature. After each act of collisions between molecules, their speed changes randomly.
- stationary equilibrium state is established in the resulting incredibly large number of collisions, the number of molecules in a given velocity range is kept constant.

MAXWELL DISTRIBUTION FUNCTION

$$f(\upsilon_x) = \frac{\mathrm{d}n_x}{n\mathrm{d}\upsilon_x} = A_1 e^{-\frac{m\upsilon_x^2}{2kT}},$$



THE DISTRIBUTION FUNCTION OF THE VELOCITY

$$f(\upsilon) = \frac{\mathrm{d}n}{n\mathrm{d}\upsilon} = \frac{4}{\sqrt{\pi}}\left(\frac{m}{2kT}\right)^{\frac{3}{2}} e^{-\frac{m\upsilon^2}{2kT}} \upsilon^2.$$

function indicates the share of single molecules of gas volume, the absolute velocities are enclosed in a single speed range, which includes the given speed.

THE BAROMETRIC FORMULA

- The atmospheric pressure at a height h due to the weight of the overlying layers of gas.

$$P = P_0 e^{-\frac{\mu g h}{RT}},$$

FIRST LAW OF THERMODYNAMICS

FIRST LAW OF THERMODYNAMICS

$$Q = \Delta U + A$$

The amount of heat imparted to the body, goes to increase the internal energy and body to perform work:

FIRST LAW OF THERMODYNAMICS

$$\Delta U = Q - A$$

the change in internal energy of a body is equal to the difference between the reported and the body heat of the produced work of body

APPLICATION OF THE FIRST LAW OF THERMODYNAMICS TO IZOPROCESSES OF IDEAL GASES

- Izo - processes in which one of the thermodynamic parameters remain constant

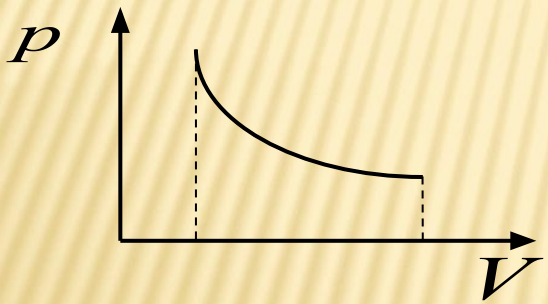
ISOTHERMAL PROCESS

- isothermal expansion $T = const$
- Conditions of flow

$$A > 0$$

$$Q = A$$

$$(Q > 0)$$



$\Delta U = 0$

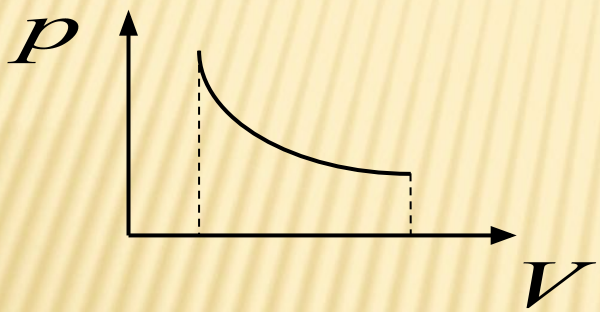
ISOTHERMAL PROCESS

- Isothermal compression

$$T = const$$

$\Delta U = 0$

- Conditions of flow

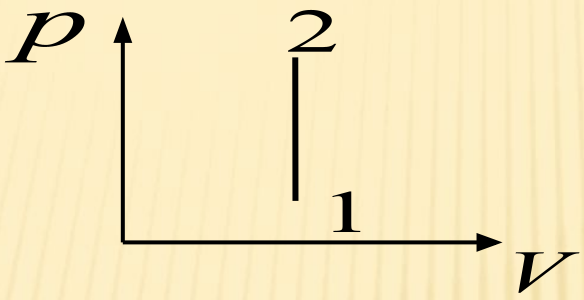


$$Q = A$$
$$(Q < 0)$$

$$A < 0$$

ISOCHORIC HEATING

$V = const$



$$Q = \Delta U$$
$$(Q > 0)$$

$$\Delta U = Q$$
$$(\Delta U > 0)$$

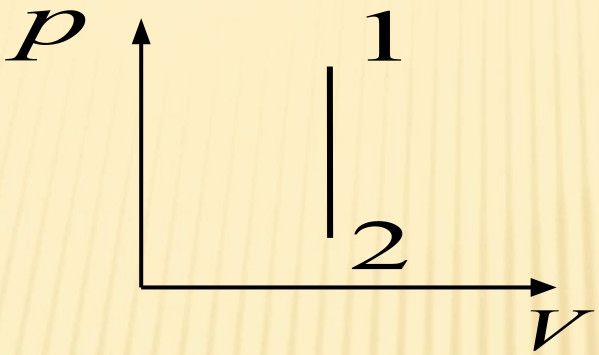
$$A = 0$$

ISOCHORIC COOLING

- $V = const$

$$Q = \Delta U$$

$$(Q < 0)$$



$$\Delta U = Q$$

$$(\Delta U < 0)$$

$$A = 0$$

ISOBAR EXTENSION AND COMPRESSION

- *Homework*

$$p = const$$

ADIABATIC PROCESS

- Adiabatic process - a process in which a heat exchange with the environment.

$$\Delta Q = 0$$

In the case of adiabatic process, the system does work due to the decrease in internal energy

$$A = -\Delta U$$

HOMEWORK

- Laws of processes

ENTROPY

- Entropy S - is the ratio of received-term or transferred heat to the tempera-D, in which this process took place.

$$\mathrm{d}S = \frac{\mathrm{d}Q}{T}$$

FOR REVERSIBLE PROCESSES, ENTROPY CHANGE:

$$\Delta S_{\text{обр}} = 0, \quad \text{т.к.} \quad \oint \frac{\mathrm{d}Q_{\text{обр}}}{T} = 0$$

This expression is called the Clausius equality.

THE SECOND LAW OF THERMODYNAMICS

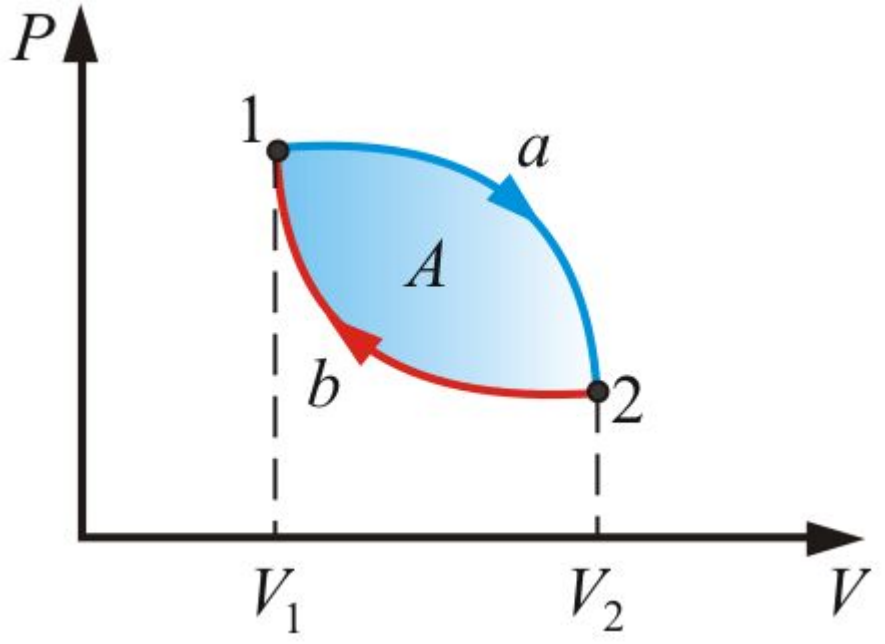
- It can not process the only result of which is the transformation of the entire heat produced by the heater in an equivalent job (wording Kelvin) 2. There can not be a perpetual motion machine of the second kind (the wording of the Thompson-Plank).
- 3. It can not process the only result of which is the transfer of energy from a cold body to a hot (Clausius formulation).

THERMAL MACHINES

- Circular process, or cycle, called such a process, in which the thermodynamic body returns to its original state.

CIRCULAR PROCESS

Cycle perpetrated an ideal gas can be divided into processes:
extensions (1 - 2)
Compression (2 - 1) of the gas



CIRCULAR PROCESS

- Circular processes underlie all heat engines: internal combustion engines, steam and gas turbines, steam and refrigeration machines, etc. As a result, a circular process, the system returns to its original state and, therefore, a complete change in the internal energy of the gas is equal to zero: dU = 0 Then the first law of thermodynamics for a circular process

$$Q = \Delta U + A = A$$

CIRCULAR PROCESS

- The process is called reversible If it proceeds in such a way that after the process, it may be conducted in the reverse direction through the same intermediate state, and that the direct process. After the circular reversible process no changes in the environment surrounding the system, will not occur. At the same time a medium is understood the set of all non-system bodies with which the system interacts directly.

CIRCULAR PROCESS

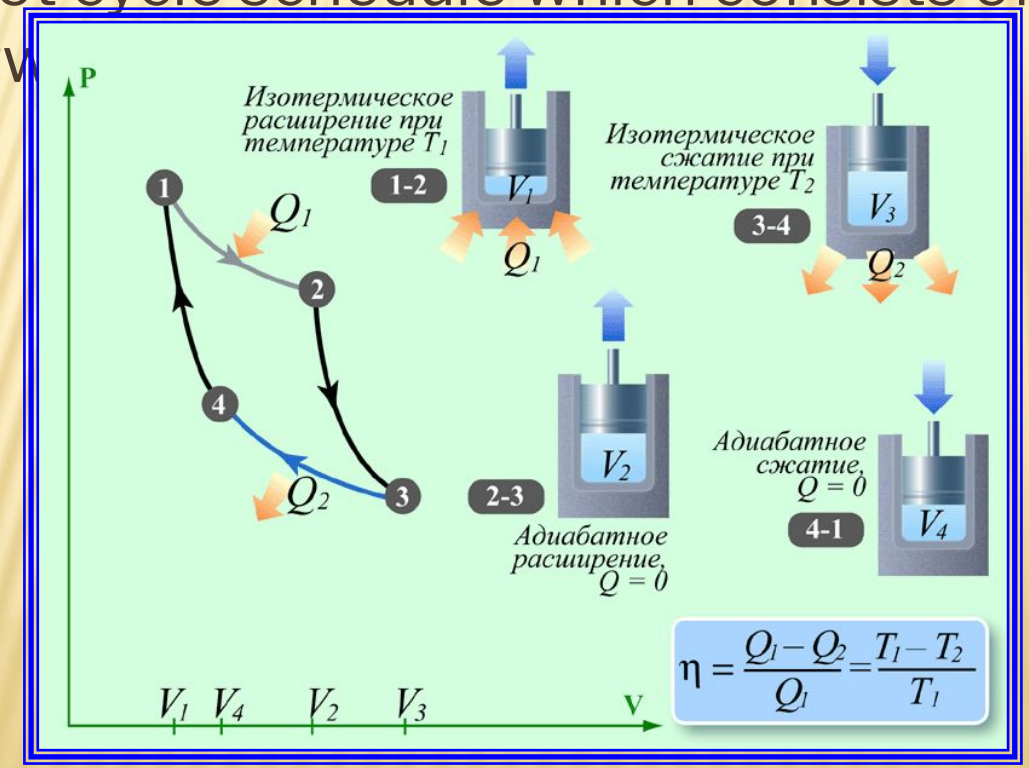
- The process is called irreversible, if it takes place, so that after the end of the system can not return to its initial state after the previous intermediate states. It is impossible to carry out an irreversible cyclic process, to anywhere in the environment remained unchanged.

HEAT ENGINES

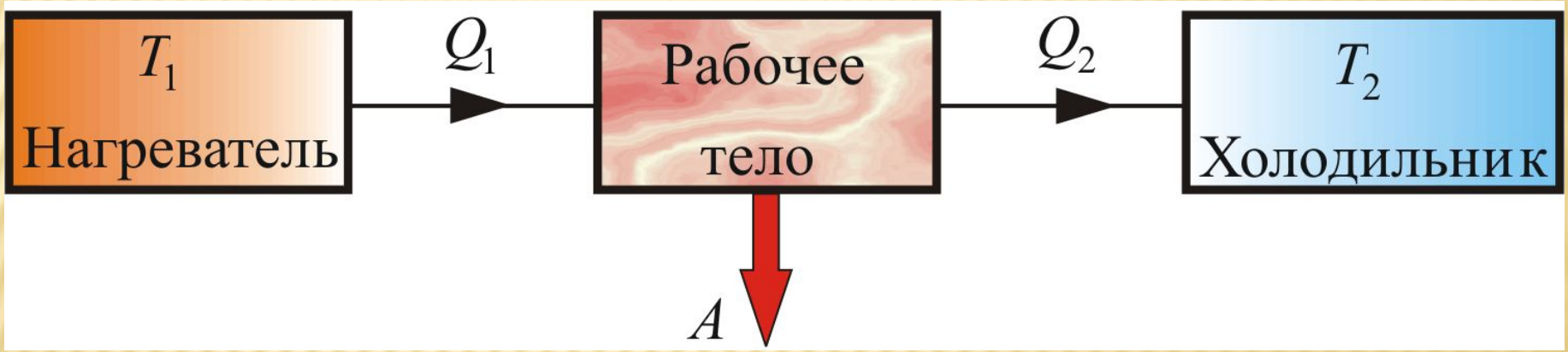
- Heat machine called a batch engine to do work on account of the resulting heat outside.

AN IDEAL HEAT ENGINE

- The greatest efficiency of the heater at predetermined temperatures T1 and T2 of the refrigerator has the heat engine working fluid which expands and contracts by the Carnot cycle schedule which consists of two isotherms and tw

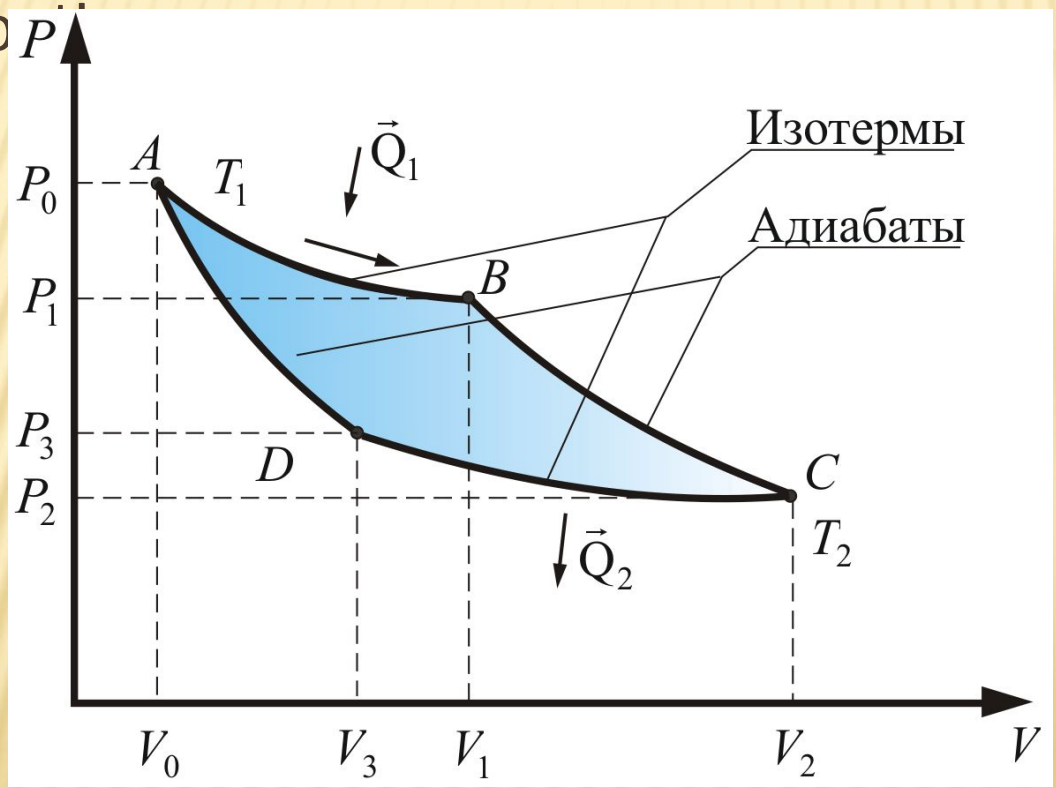


CARNOT CYCLE



CARNOT CYCLE

- Cycle, Carnot studied, is the most economical and is a cyclic process consisting of two isotherms and two adiab



EFFICIENCY CARNOT MACHINE

$$\eta = \frac{A}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}.$$

REAL GASES

REAL GASES

- Equation Mendeleev - Clapeyron - the simplest, most reliable and well-known equation of state of an ideal gas.

$$PV = \frac{m}{\mu} RT$$

Real gases are described by the equation of state of an ideal gas is only approximate, and deviations from the ideal behavior become noticeable at high pressures and low temperatures, especially when the gas is close to condensation.

REAL GASES

- The First Amendment to the ideal gas equation of state is considering its own volume occupied by the molecules of a real gas. In equation Dupre (1864)

$$P(V - \nu b) = \nu RT$$

the constant b takes into account its own molar volume of molecules.

REAL GASES

- As the temperature decreases the intermolecular interaction in real gases leads to condensation (fluid generation). Intermolecular attraction is equivalent to the existence of some of the gas internal pressure P * (sometimes called static pressure). Initially P * value was taken into account in general terms in the equation Girne (1865)

$$(P + P^*)(V - \nu b) = \nu RT$$

VAN DER WAALS EQUATION

- Van der Waals gave a functional interpretation of the internal pressure. According to the model of Van der Waals attractive forces between molecules (Van der Waals force) is inversely proportional to the sixth power of the distance between them, or a second degree of the volume occupied by the gas. It is also believed that the force of attraction added to the external pressure.

VAN DER WAALS EQUATION

- With these considerations in mind an ideal gas equation of state is transformed into the equation of van der Waals forces:

$$(V - \nu b)\left(P + \frac{\nu^2 a}{V^2}\right) = \nu RT$$

or for one mole

$$(V_m - b)\left(P + \frac{a}{V_m^2}\right) = \nu RT$$

REAL GASES

- Real gases - gases whose properties depend on the molecular interaction. Under normal conditions, when the average potential energy of intermolecular interaction is much smaller than the average kinetic energy of the molecules, the properties of real and ideal gases differ slightly. The behavior of these gases varies sharply at high pressures and low temperatures where quantum effects begin to appear.

VAN DER WAALS FORCE

- Van der Waals to explain the properties of real gases and liquids, suggested that at small distances between molecules are repulsive forces, which are replaced with increasing distance attraction forces.

VAN DER WAALS FORCE

- Intermolecular interactions-tion are electrical in nature and consist of attractive forces (orientation, induction, dispersion) and repulsive forces.

THE INTERNAL ENERGY OF THE GAS VAN DER WAALS

- The energy of one mole of a gas van der Waals force is composed of:
- the internal energy of the gas molecules;
- the kinetic energy of the thermal motion of the center of mass of molecules
- the potential energy of mutual attraction of molecules

VAN DER WAALS FORCE

- The principal value of the van der Waals equation is determined by the following factors 1) The equation was derived from the model of the properties of real gases and liquids, and not the result of empirical selection function f (P, V, T), which describes the properties of real gases;

VAN DER WAALS FORCE

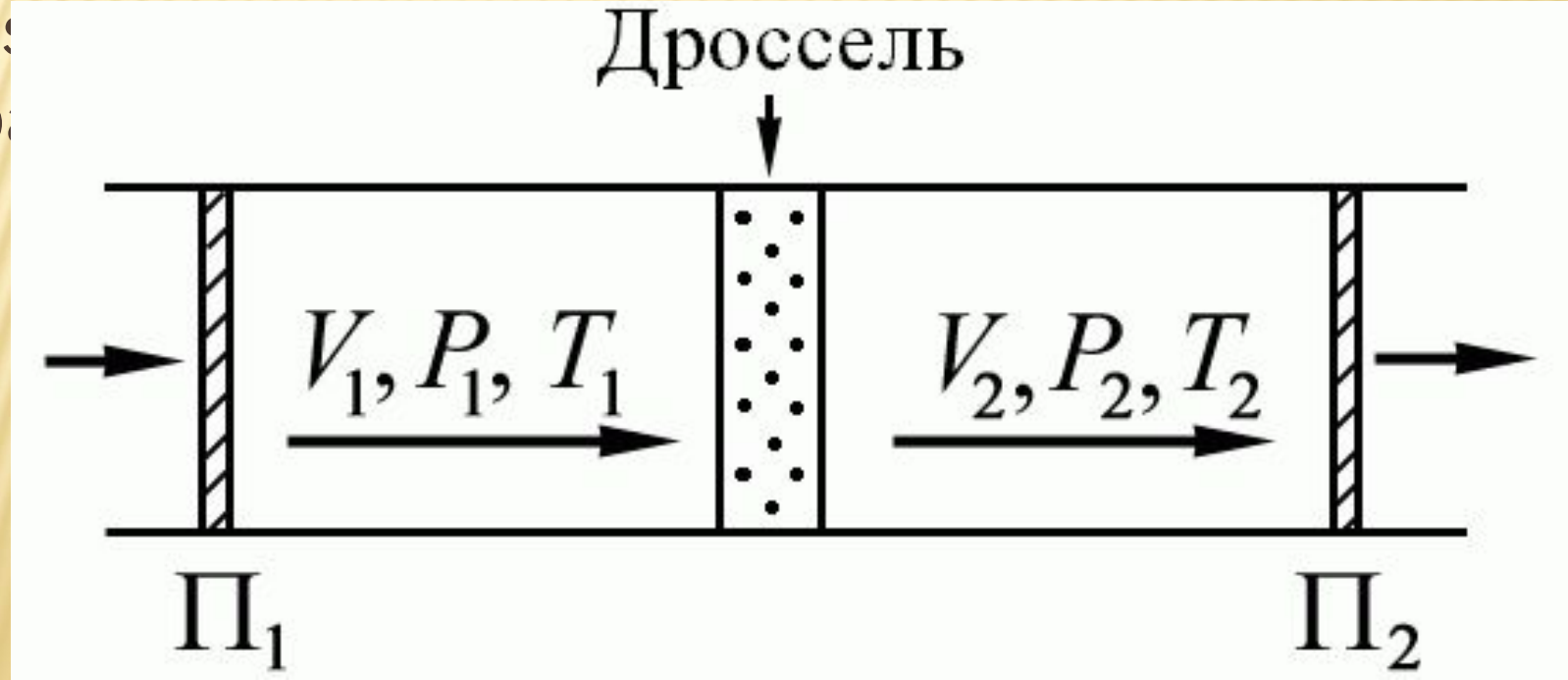
- 2) The equation for a long time regarded as a general form of the equation of state of real gases, on the basis of which it was built many other equations of state;3) Using the equation of van der Waals forces were the first to describe the phenomenon of transfer of gas into the liquid and analyze critical phenomena. In this regard, the Van der Waals has an advantage even before the more accurate equations in virial form.

JOULE-THOMSON EFFECT

- If the ideal gas adiabatically expands and performs work at the same time, then it is cooled, as in this case, the work is done at the expense of its internal energy.
- A similar process, but with a real gas - adiabatic expansion of a real gas to the commission of external forces positive work

JOULE-THOMSON EFFECT

- Joule-Thomson effect is to change the temperature of the gas as a result of a slow flow of gas under a constant pressure drop through the reactor - a local obstacle to the gas flow, such as
p



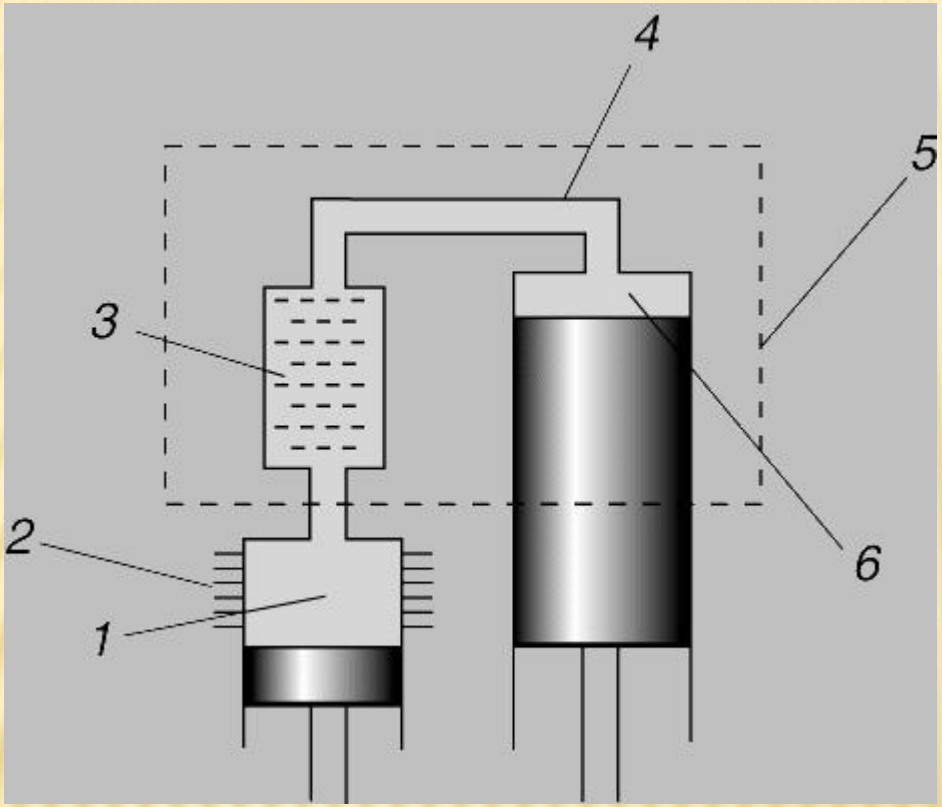
JOULE-THOMSON EFFECT

- Joule-Thomson effect indicates the presence of gas in the intermolecular forces. Gas performs external work - subsequent layers of gas pushed past, and perform work force of the external pressure, providing a stationary flow of gas itself. The work of pushing through the throttle portion of gas volume V1 at a pressure P1 is P1V1, throttle this portion of gas occupies a volume V2 and does work P2V2.

LIQUEFACTION OF GASES

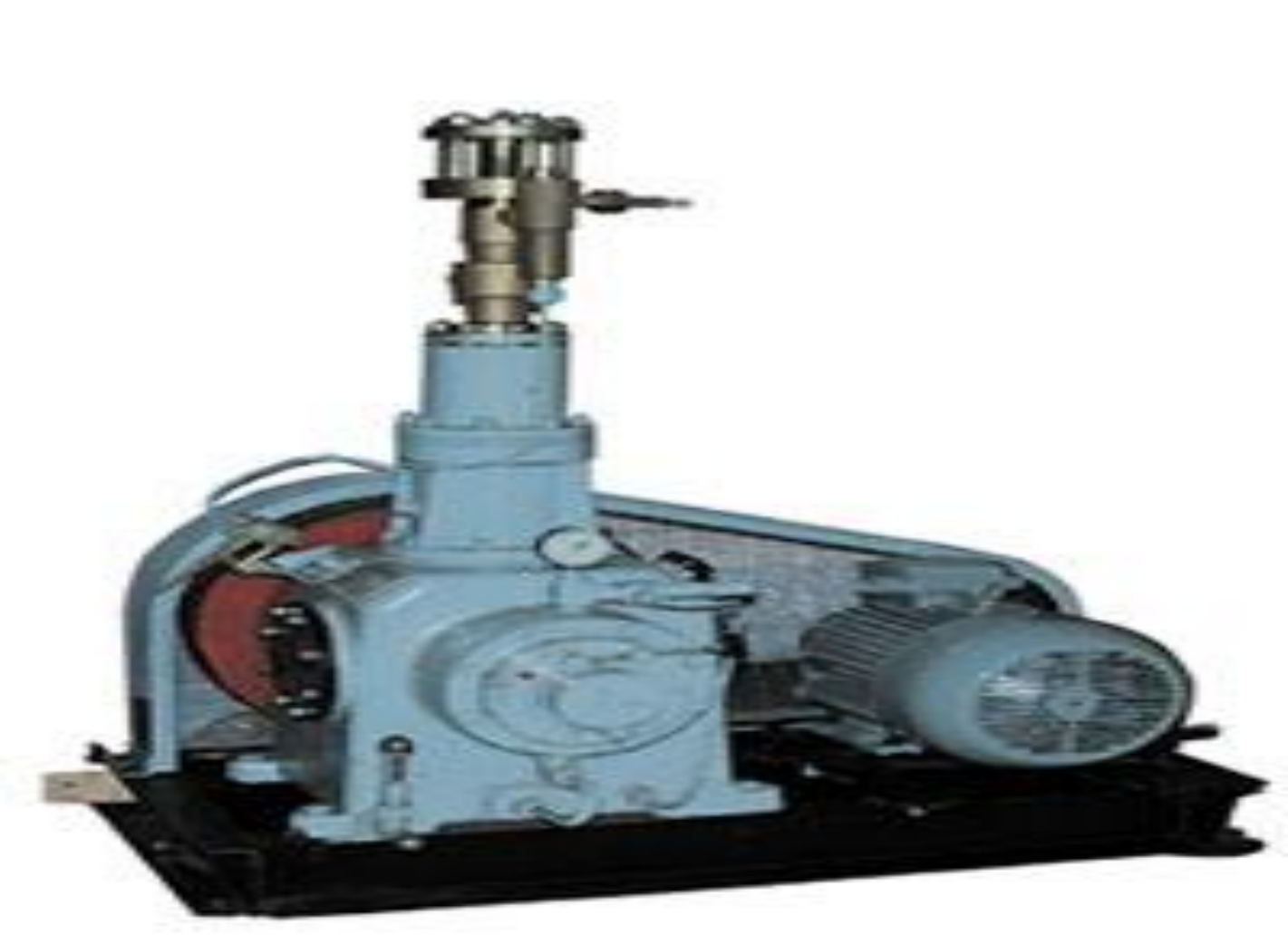
- The conversion of any gas in the liquid - gas liquefaction - is possible only at temperatures below the critical value.

LIQUEFACTION OF GASES



1 - cylinder compressor; 2 - cooling fins; 3 - regenerator; 4 - head cold; 5 - insulation; 6 - cylinder expander.

LIQUEFACTION OF GASES



ELECTRICITY

NATURE

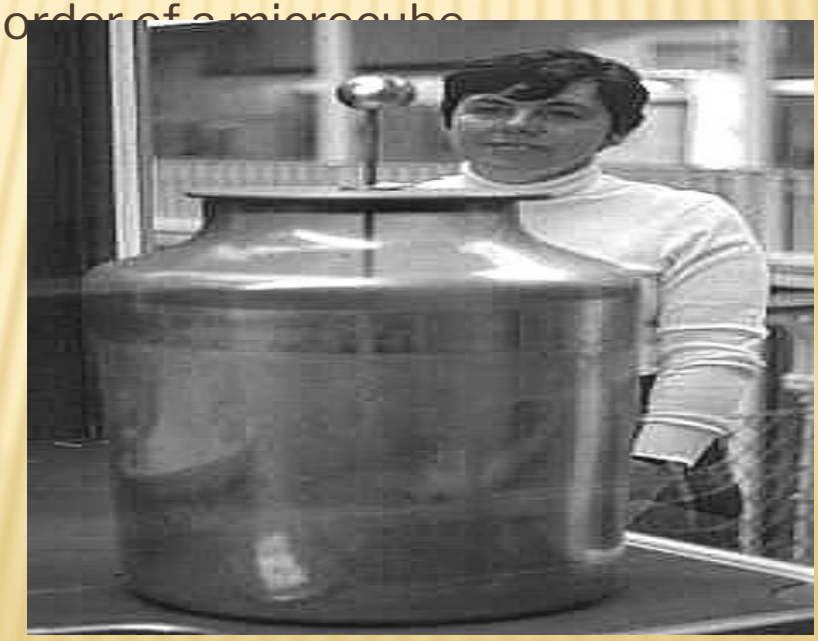
- The first known manifestations of "animal electricity" were discharges of electric fishes. The electric catfish was depicted even on ancient Egyptian tombs, and Galen (130-200 years of our era) recommended "electrotherapy" with the help of these fishes, who underwent medical practice at gladiatorial battles in Ancient Rome.

HISTORY

- In the years 1746-54. Franklin explained the action of the Leyden jar, built the first flat capacitor consisting of two parallel metal plates separated by a glass layer, invented a lightning rod in 1750, proved in 1753 the electrical nature of lightning (experience with a kite) and the identity of terrestrial and atmospheric electricity. In 1750, he developed a theory of electrical phenomena - the so-called "unitary theory", according to which electricity represents a special thin liquid, piercing all the bodies

HISTORY

- The Leiden Bank was invented in 1745 by an independent Dutch professor Peter Van Mushenbrock (1692-1761) and German prelate Ewald George von Kleist. The dielectric in this condenser was the glass of the vessel, and the plates were water in the vessel and the palm of the experimenter, which held the vessel. The output of the inner lining was a metallic conductor, passed into a vessel and immersed in water. In 1746, various modifications of the Leyden jar appeared. The Leiden bank allowed to store and store relatively large charges, of the order of a microcube



ELECTRIC CHARGE

- Electric charges do not exist by themselves, but are internal properties of elementary particles - electrons, protons, etc.
- Experienced in 1914, the American physicist R. Milliken showed that
- Electric charge is discrete.
- The charge q of any body is an integral multiple of the elementary electric charge: q = n × e.

$$e = 1{,}6 \cdot 10^{-19}\ \text{Кл}$$

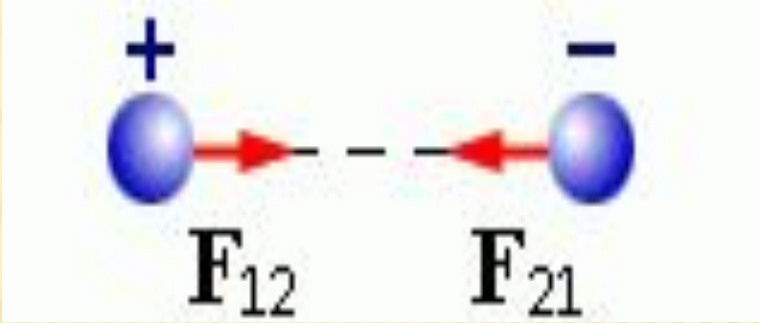
LAW OF CONSERVATION OF CHARGE

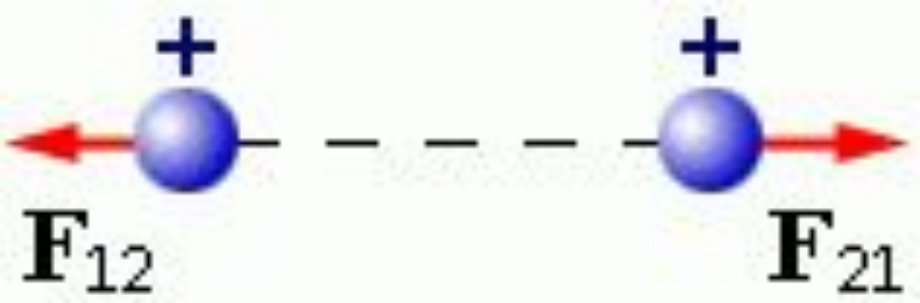
- The law of conservation of charge is one of the fundamental laws of nature, formulated in 1747 by B. Franklin and confirmed in 1843 by M. Faraday: the algebraic sum of charges arising in any electric process on all bodies participating in the process is zero.
- The total electric charge of a closed system does not change

ELECTRIC CHARGE

- Electrostatics is a section that studies static (immobile) charges and associated electric fields.

LAWS





THE COULOMB LAW

- A great contribution to the study of phenomena of electrostatics was made by the famous French scientist
- S. Coulomb.
- In 1785, he experimentally established the law of interaction of fixed point electric charges.

INTERACTION OF ELECTRIC CHARGES IN A VACUUM.

- A point charge (q) is a charged body whose dimensions are negligibly small in comparison with the distance to other charged bodies with which it interacts.

THE COULOMB LAW

- The force of interaction of point charges in a vacuum is proportional to the value of the charges and inversely proportional to the square of the distance between them.

$$F = k_0 \frac{|q_1 q_2|}{r^2}$$

COEFFICIENT

- Where ε0 is the electric constant;
- 4p here express the spherical symmetry of Coulomb's law.

$$k_0 = \frac{1}{4\pi\varepsilon_0} = 9 \cdot 10^9 \ \frac{\text{Н} \cdot \text{м}^2}{\text{Кл}^2}$$

ELECTROSTATIC FIELD STRENGTH

- Around the charge there is always an electric field, the main property of which is that any other charge placed in this field is acted upon by force.
- Electric and magnetic fields are a special case of a more general - electromagnetic field (EMF).
- They can breed each other, turn into each other.
- If the charges do not move, then the magnetic field does not arise.

ELECTROSTATIC FIELD STRENGTH

- The force characteristic of the field created by the charge q is the ratio of the force acting on the test charge q 'placed at a given point of the field to the value of this charge, called the electrostatic field strength, i.e.

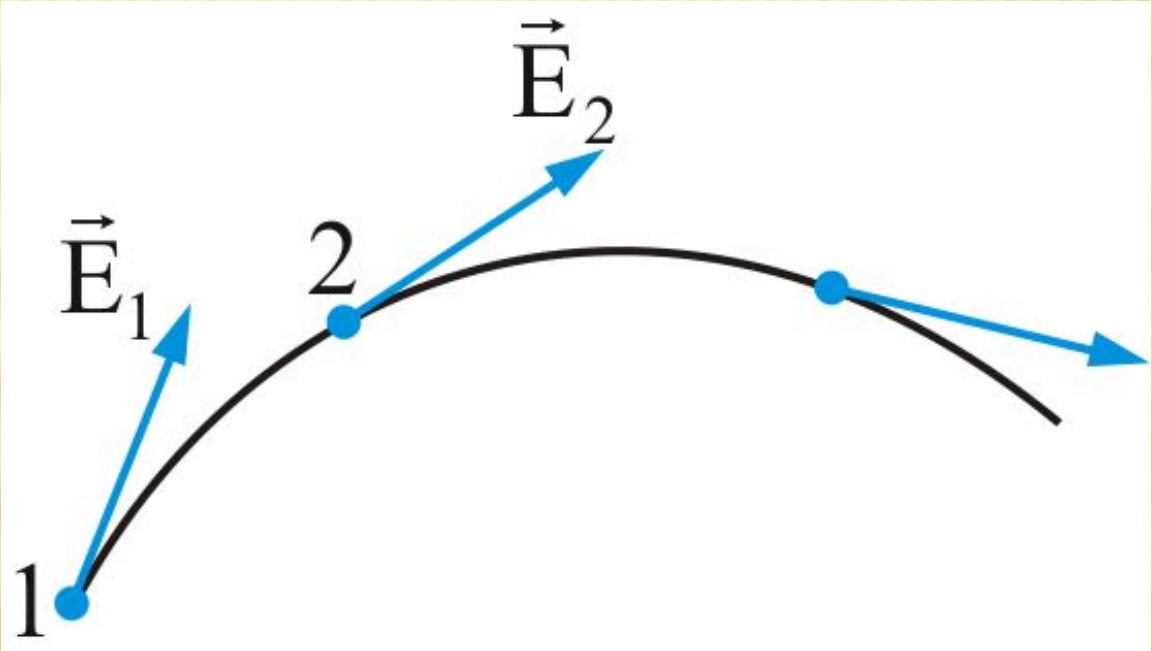
$$E = \frac{F}{q'} = \frac{q}{4\pi\varepsilon_0 r^2}$$

FIELD LINES OF ELECTROSTATIC FIELD

- The Ostrogradsky-Gauss theorem, which we shall prove and discuss later, establishes the connection between electric charges and the electric field. It is a more general and more elegant formulation of Coulomb's law.

LINES OF FORCE

- Lines of force are lines tangent to which at any point of the field coincides with the direction of the tension vector



THE OSTROGRADSKY-GAUSS THEOREM

- So, by definition, the flux of the electric field strength vector is equal to the number of tension lines crossing the surface S.

THE OSTROGRADSKY-GAUSS THEOREM

$$\Phi_E = \oint_S E_n \mathrm{d}S = \frac{\sum q}{\varepsilon_0}$$

- The flux of the electric field strength vector through a closed surface in a vacuum is equal to the algebraic sum of all charges located inside the surface divided by ε0.

$$\Phi_E = \frac{1}{\varepsilon_0} \int_V \rho \mathrm{d}V$$

POTENTIAL

- The work of electrostatic forces does not depend on the shape of the path, but only on the coordinates of the initial and final points of displacement. Consequently, the field strengths are conservative, and the field itself is potentially.

POTENTIAL DIFFERENCE

$$\varphi = \frac{W}{q'}.$$

- From this expression it follows that the potential is numerically equal to the potential energy that a unit positive charge possesses at a given point of the field.

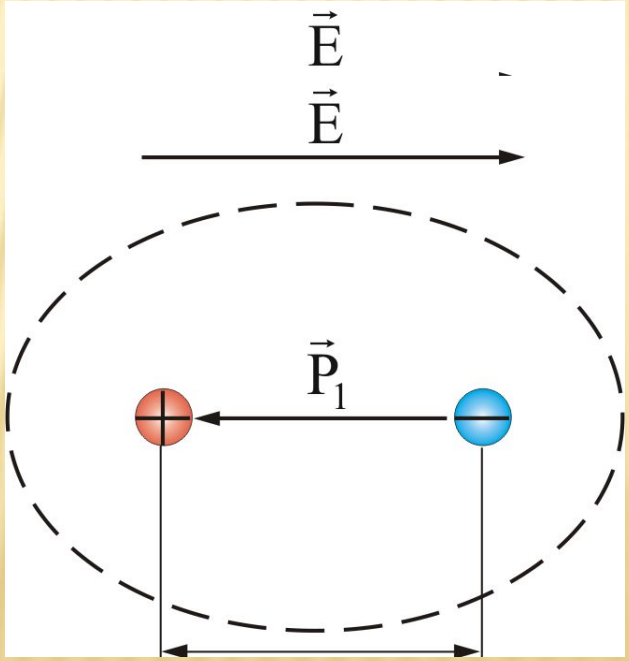
DIELECTRICS IN THE ELECTROSTATIC FIELD

- In an ideal dielectric, free charges, that is, capable of moving over significant distances (exceeding the distances between atoms), no.
- But this does not mean that a dielectric placed in an electrostatic field does not react to it, that nothing happens in it.

DIELECTRICS IN THE ELECTROSTATIC FIELD

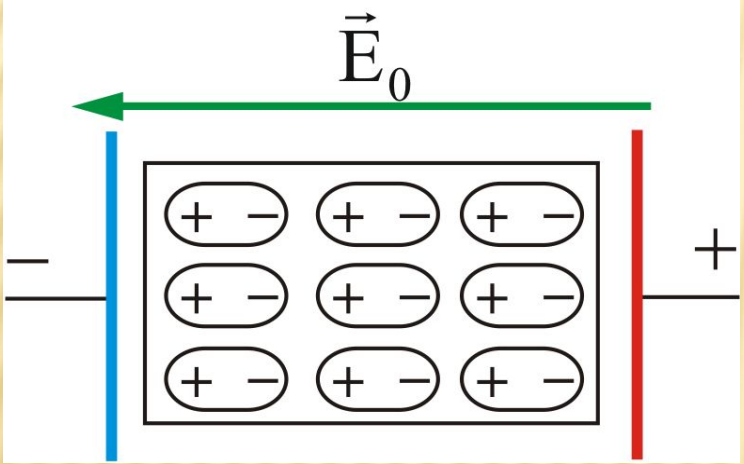
- The displacement of electrical charges of a substance under the action of an electric field is called polarization.

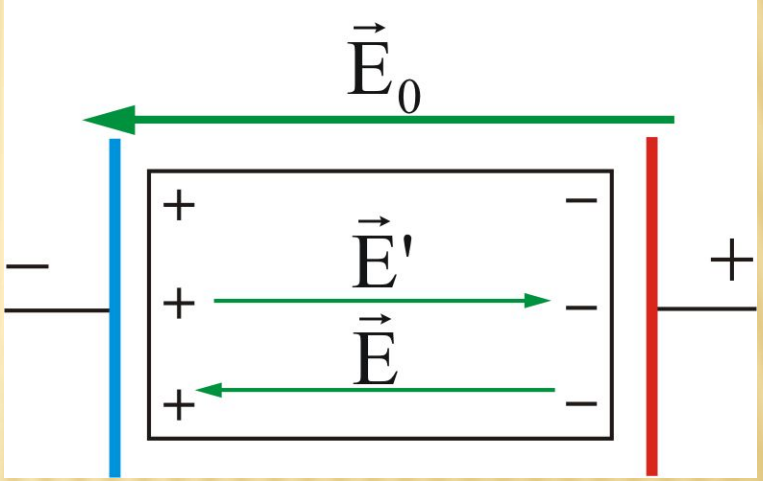
- The ability to polarize is the main property of dielectrics.



DIELECTRICS IN THE ELECTROSTATIC FIELD

- Inside the dielectric, the electric charges of the dipoles cancel each other out. But on the outer surfaces of the dielectric, adjacent to the electrodes, charges of the opposite sign appear (surface-bound charges).





DIFFERENT KINDS OF DIELECTRICS

- In 1920, spontaneous (spontaneous) polarization was discovered.
- The whole group of substances was called ferroelectrics (or ferroelectrics).
- All ferroelectrics exhibit a sharp anisotropy of properties (ferroelectric properties can be observed only along one of the crystal axes). In isotropic dielectrics, the polarization of all molecules is the same, for anisotropic ones - polarization, and consequently the polarization vector in different directions is different.

DIFFERENT KINDS OF DIELECTRICS

- Among dielectrics, there are substances called electret-dielectrics, which preserve the polarized state for a long time after removal of the external electrostatic field (analogues of permanent magnets).

DIFFERENT KINDS OF DIELECTRICS

- Some dielectrics are polarized not only under the action of the electric field, but also under the action of mechanical deformation. This phenomenon is called the piezoelectric effect.
- The phenomenon was discovered by the brothers Pierre and Jacques Curie in 1880.

DIFFERENT KINDS OF DIELECTRICS

- Pyroelectricity - the appearance of electrical charges on the surface of some crystals when they are heated or cooled.
- When heated, one end of the dielectric is charged positively, and when cooled, it is also negative.
- The appearance of charges is associated with a change in the existing polarization as the temperature of the crystals changes.

ELECTRIC CURRENT IN GASES. GAS DISCHARGES AND THEIR APPLICATIONS

THE PHENOMENON OF IONIZATION AND RECOMBINATION IN GASES

- The ionization process consists in the fact that under the action of high temperature or some rays the molecules of the gas lose electrons and thereby turn into positive ions.
- The current in gases is a counterflow of ions and free electrons.
- Simultaneously with the ionization process, there is a reverse process of recombination (otherwise - molization).
- Recombination is a neutralization when different ions are encountered, or a reunion of an ion and an electron into a neutral molecule (atom).
- The factors under the action of which ionization occurs in a gas are called external ionizers, and the conductivity that occurs here is called a non-self-sustaining conductivity.

SELF-CONTAINED GAS DISCHARGE

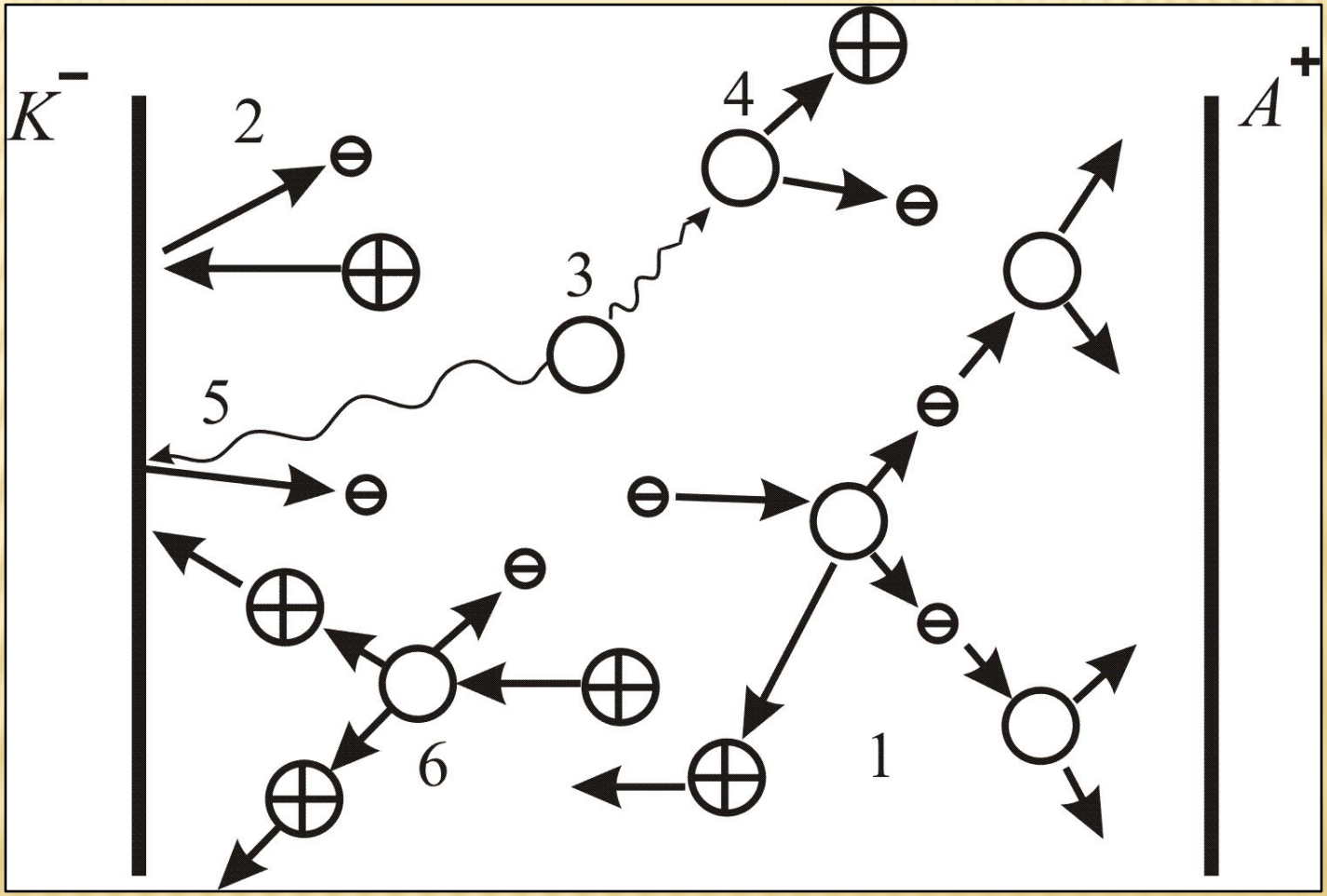
- An independent discharge is a gas discharge in which the current carriers arise as a result of those processes in the gas that are due to the voltage applied to the gas.
- That is, this discharge continues after the ionizer stops.

SELF-CONTAINED GAS DISCHARGE

- When the interelectrode gap is covered by a completely conducting gas-discharge plasma, its breakdown occurs.

- The voltage at which the breakdown of the interelectrode gap occurs is called the breakdown voltage.

CONDITIONS FOR THE FORMATION AND MAINTENANCE OF AN INDEPENDENT GAS DISCHARGE



TYPES OF CHARGE

- Depending on gas pressure, electrode configuration and external circuit parameters, there are four types of stand-alone discharges:
- Glow charge;
- Spark charge;
- Arc charge;
- Corona charge.

GLOWING CHARGE

- he glow charge occurs at low pressures (in vacuum tubes).
- It can be observed in a glass tube with flat metal electrodes soldered at the ends.
- Near the cathode is a thin luminous layer, called a cathode luminous film

SPARK CHARGE

- The spark charge arises in the gas, usually at pressures on the order of atmospheric Rm.
- It is characterized by a discontinuous form.
- In appearance, the spark discharge is a bundle of bright, zigzag-shaped branched thin strips instantly piercing the discharge gap, rapidly dying out and constantly replacing each other.
- These strips are called spark channels.

ARC CHARGE

- If, after obtaining a spark charge from a powerful source, gradually reduce the distance between the electrodes, the discharge from the intermittent becomes continuous a new form of gas charge, called an arc charge, arises.

CORONA DISCHARGE

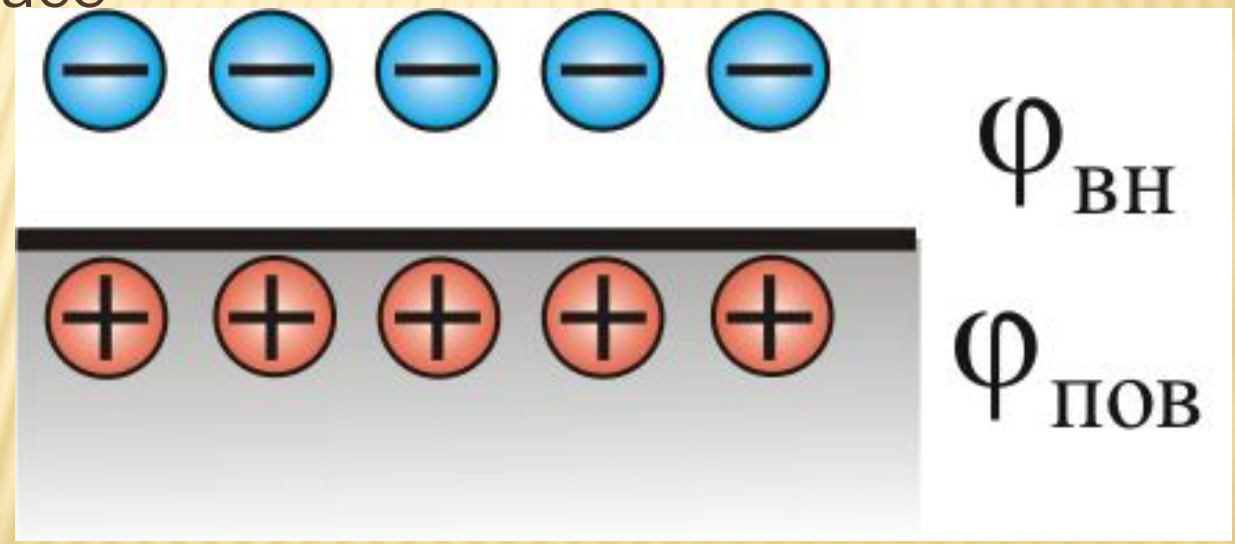
- Corona discharge occurs in a strong non-uniform electric field at relatively high gas pressures (of the order of atmospheric pressure).
- Such a field can be obtained between two electrodes, the surface of one of which has a large curvature (thin wire, tip).

APPLICATION OF GAS CHARGE

- Gas discharge devices are very diverse, and differ in the type of discharge used.
- They are used to stabilize the voltage, protect against overvoltage, perform switching functions, indicate the electrical state
- Recently, to enhance the protection of vulnerable and responsible objects, for example, missile launchers, various forms of lightning control are being implemented, in particular laser lightning initiation.
- Laser initiation is based on the creation of an ionized channel in the air by means of laser radiation.

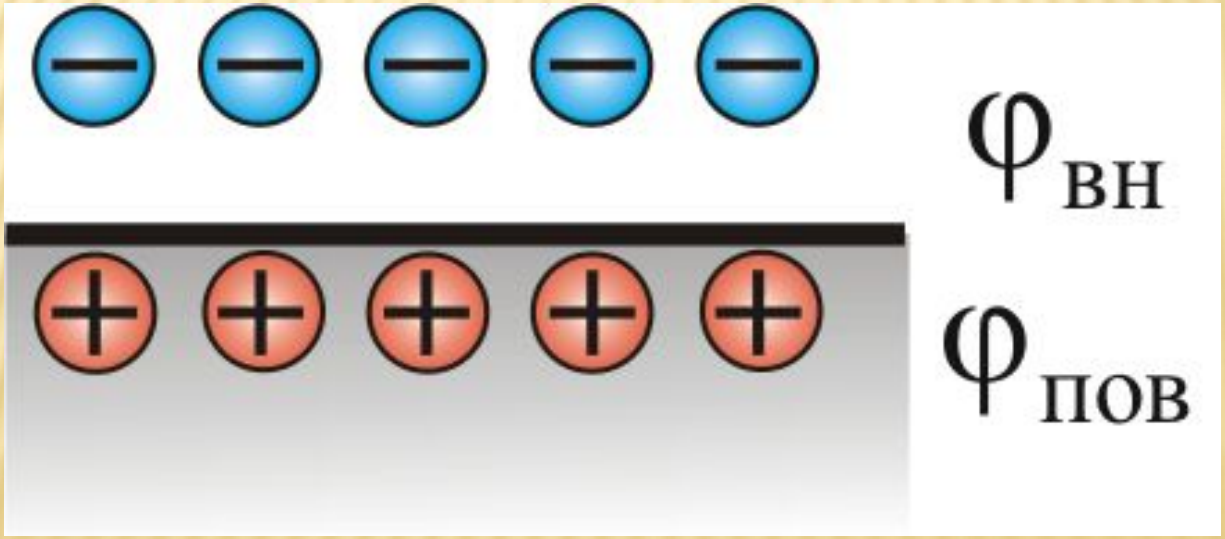
ELECTRON EMISSION FROM CONDUCTORS

- The electron is free only within the boundaries of the metal. As soon as he tries to cross the "metal-vacuum" boundary, a Coulomb force of attraction arises between the electron and the excess positive charge formed on the surface



ELECTRON EMISSION FROM CONDUCTORS

- An electron cloud is formed near the surface, and a double electric layer is formed at the interface
- Potential difference



THERMIONIC EMISSION

- The magnitude of the work function depends on the chemical nature of the substance, on its thermodynamic state, and on the state of the interface.
- If the energy sufficient to accomplish the work function is communicated to electrons by heating, then the process of electron exit from the metal is called thermionic emission.

COLD AND EXPLOSIVE EMISSION

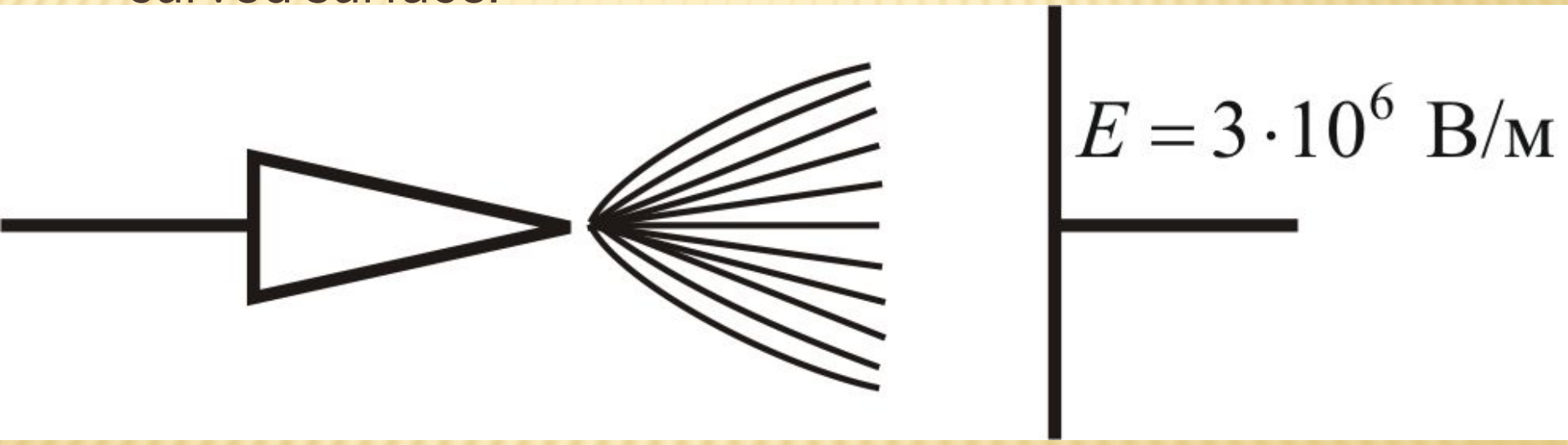
- Electronic emission caused by the action of electric field forces on free electrons in a metal is called cold or field emission.
- To do this, the field strength must be sufficient and the condition

$$A_{\text{вых}} = e\left(\varphi_{\text{вн}} - \varphi_{\text{пов}}\right) \leq eEd,$$

- Here d is the thickness of the double electric layer at the media interface.

AUTO-ELECTRON EMISSION

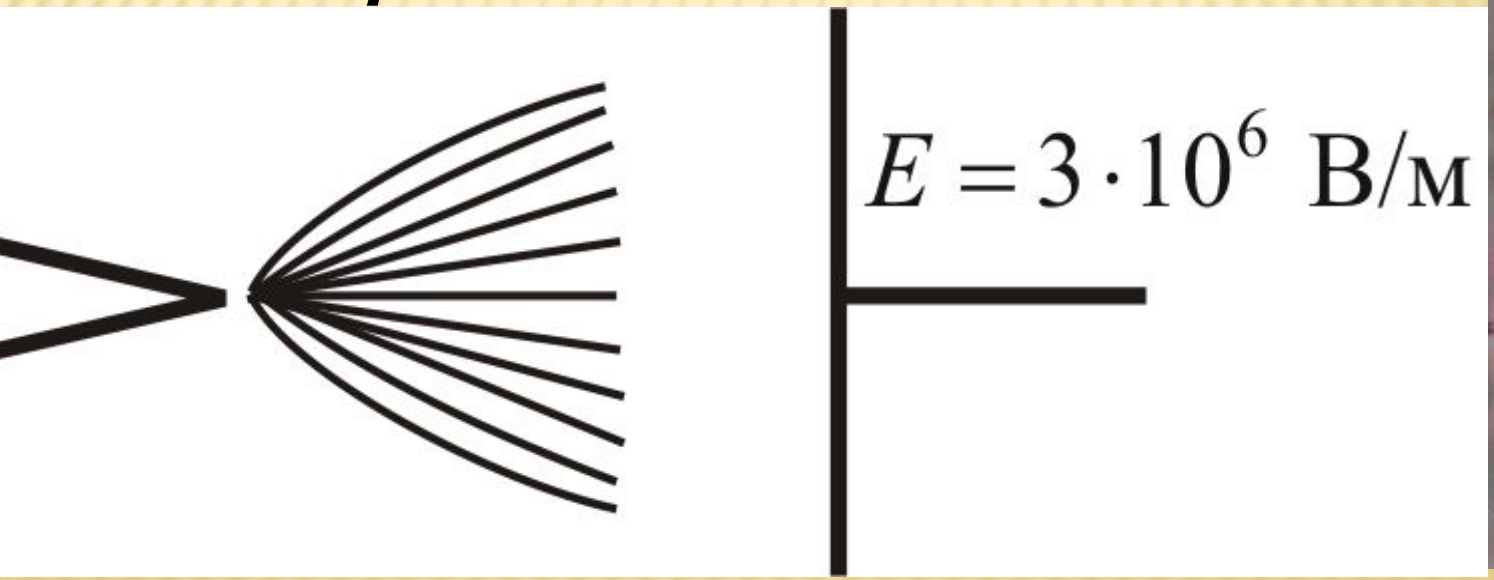
- The field emission can be observed in a well-evacuated vacuum tube, with the cathode serving as a tip, and the anode as a conventional electrode with a flat or slightly curved surface.

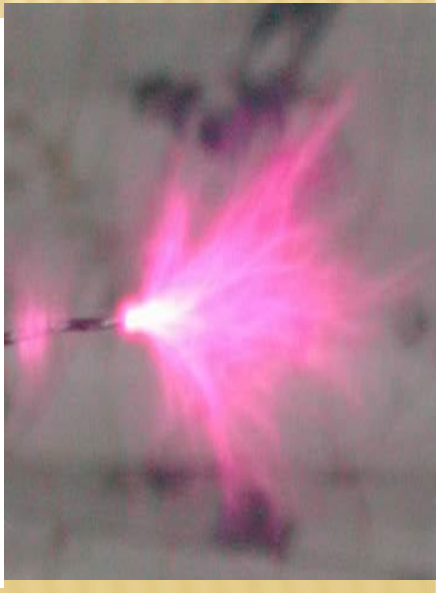


AUTO-ELECTRON EMISSION

- The electric field strength on the surface of the tip with a radius of curvature r and potential U relative to the anode is

$$E = \frac{U}{r}.$$





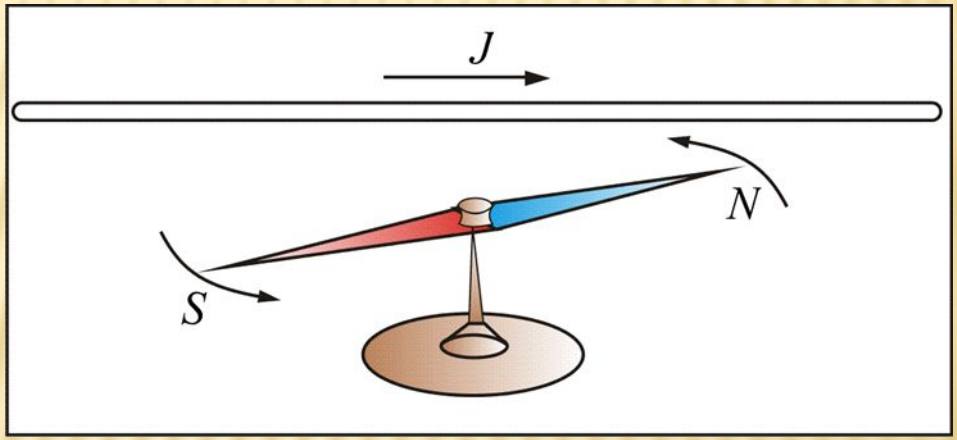
MAGNETISM

MAGNETIC INTERACTIONS

- A magnetic field arises in the space surrounding magnetized bodies.
- A small magnetic needle placed in this field is installed at each of its points in a very definite way, thereby indicating the direction of the field.
- The end of the arrow, which in the magnetic field of the Earth points to the north, is called the north, and the opposite - the south.

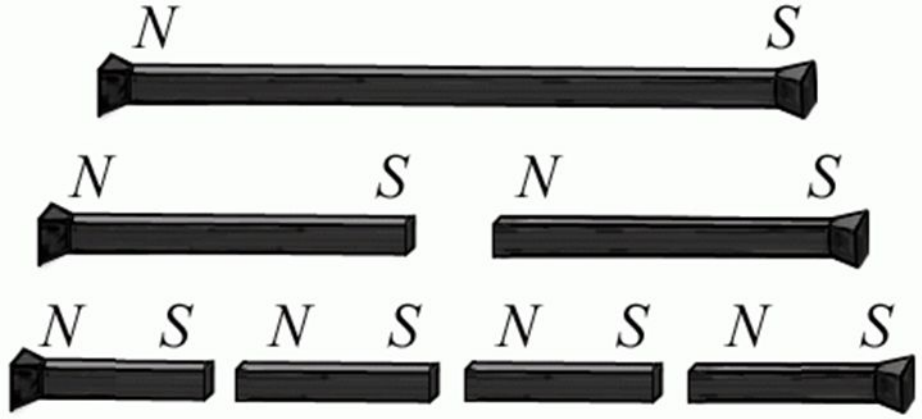
WHEN THE MAGNETIC NEEDLE DEVIATES FROM THE DIRECTION OF THE MAGNETIC FIELD, THE ARROW ACTS

MECHANICAL TORQUE MCR, PROPORTIONAL TO THE SINE OF THE DEVIATION ANGLE A AND TENDING TO TURN IT ALONG THE SPECIFIED DIRECTION.



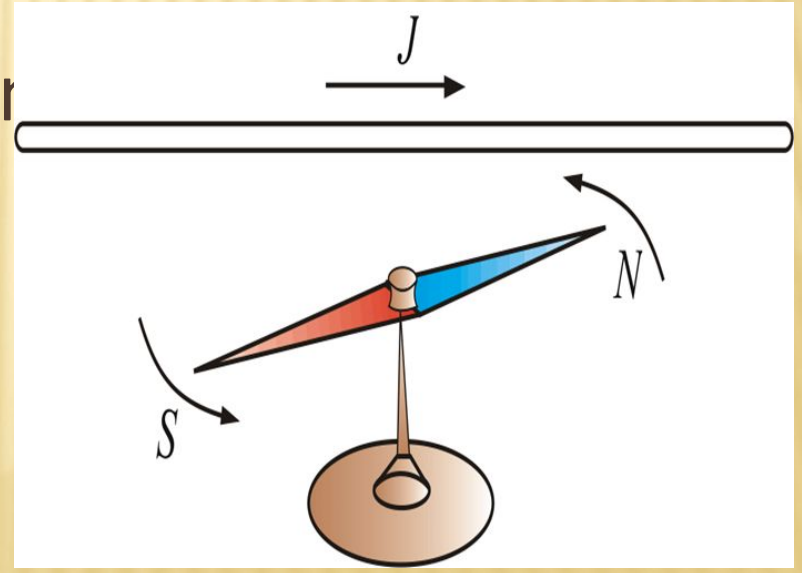
THE DIFFERENCE BETWEEN PERMANENT MAGNETS AND ELECTRIC DIPOLES IS AS FOLLOWS:

- An electric dipole always consists of charges of equal magnitude and opposite in sign.
- The permanent magnet, being cut in half, turns into two smaller magnets, each of which has both the north and south poles.



DISCOVERY OF OERSTED

- When placing a magnetic needle in the immediate vicinity of a conductor with a current, he found that when a current flows through a conductor, the arrow deflects; after the current is turned off, the arrow returns to its original position .
- From the described exper
- Oersted concludes:
- around rectilinear
- conductor with current
- there is a magnetic field.



MAGNETIC INDUCTION $\vec{B}$

- force characteristic of the magnetic field, it can be represented using magnetic field lines.
- Since M is the moment of force and P_m the magnetic moment is the characteristics of the rotational motion, it can be assumed that the magnetic field is vortex.

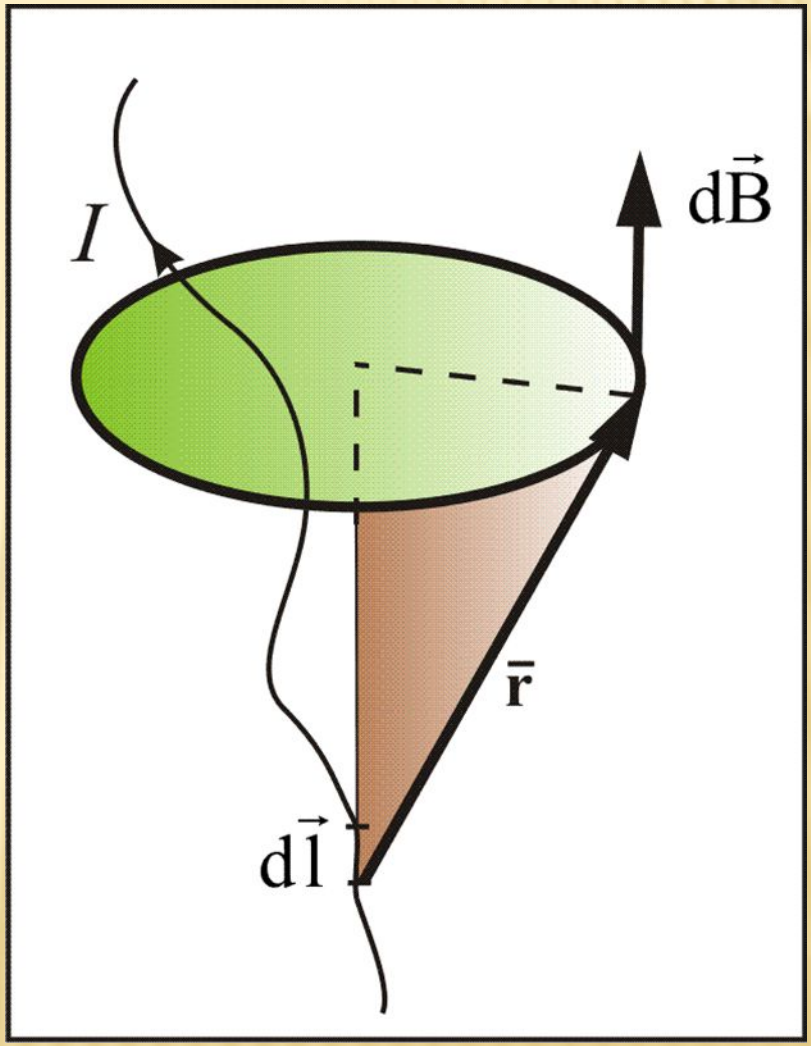
BIO – SAVARD – LAPLACE-AMPER LAW

- In 1820, French physicists Jean Baptiste Biot and Felix Savard conducted studies of the magnetic fields of currents of various shapes. A French mathematician Pierre Laplace summarized these studies.

BIO – SAVARD – LAPLACE-AMPER LAW

$$\mathrm{d}B = k\frac{I\mathrm{d}l}{r^2}$$

$$\mathrm{d}\vec{\mathrm{B}} = k\frac{I[\mathrm{d}\vec{\mathrm{l}},\vec{\mathrm{r}}]}{r^3}.$$



BIO – SAVARD – LAPLACE-AMPER LAW

- Here: I - current;
- - vector coinciding with the elementary portion of the current and directed in the direction to which the current flows;
- - the radius vector drawn from the current element to the point at which we determine;
- r is the module of the radius vector;
- k - proportionality coefficient, depending on the system of units.

FIELD CONDUCTOR ELEMENT WITH CURRENT

$$dB = \frac{\mu_0}{4\pi} \cdot \frac{Idl}{r^2} \sin\alpha$$

THE BIO – SAVARD – LAPLACE LAW FOR VACUUM CAN BE WRITTEN AS FOLLOWS.

$$\mathrm{d}B = \frac{\mu_0}{4\pi}\frac{I\mathrm{d}l\sin\alpha}{r^2},$$

$$\mu_0 = 4\pi \cdot 10^{-7}\ \text{Гн/м}$$

magnetic constant.

MAGNETIC FIELD STRENGTH

- The magnetic field is one of the forms of manifestation of the electromagnetic field, a feature of which is that this field acts only on moving particles and bodies with an electric charge, as well as on magnetized bodies.

A MAGNETIC FIELD

- The magnetic field is created by conductors with current, moving electric charged particles and bodies, as well as alternating electric fields.
- The force characteristic of the magnetic field is the vector of magnetic induction of the field created by a single charge in a vacuum.

$$\vec{B} = \frac{\mu_0}{4\pi} \frac{q[\vec{\upsilon}, \vec{r}]}{r^3}$$

GAUSS THEOREM FOR MAGNETIC INDUCTION VECTOR

$$\Phi_B = \oint_S \vec{B} d\vec{S} = 0$$

ACCELERATOR CLASSIFICATION

- Accelerators of charged particles are devices in which beams of high-energy charged particles (electrons, protons, mesons, etc.) are created and controlled under the action of electric and magnetic fields.

ANY ACCELERATOR IS CHARACTERIZED BY:

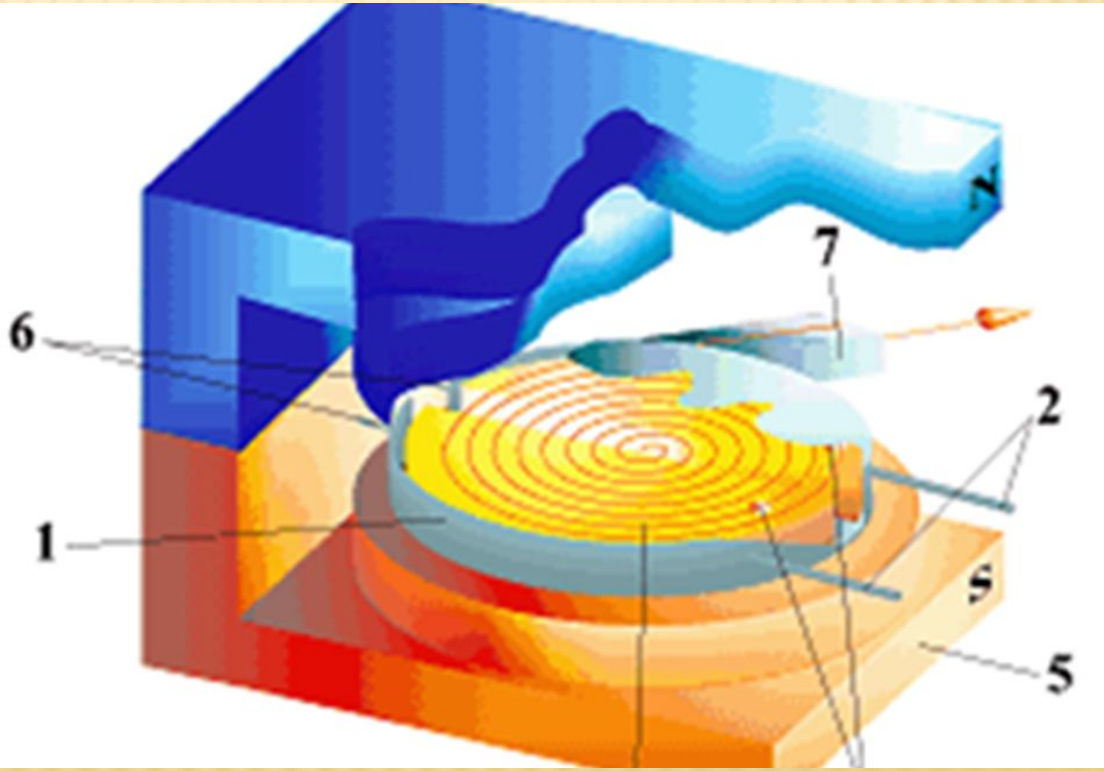
- type of accelerated particles
- dispersion of particles by energies,
- beam intensity.
- Accelerators are divided into
- continuous (uniform in time beam)
- impulse (particles in them are accelerated in portions - impulses). The latter are characterized by a pulse duration.

ANY ACCELERATOR IS CHARACTERIZED BY

- According to the shape of the trajectory and the acceleration mechanism of the particles, the accelerators are divided into
- linear,
- cyclic
- induction.
- In linear accelerators, particle trajectories are close to straight lines,
- in the cyclic and inductive trajectories of the particles are circles or spirals.

CYCLIC BOOSTERS

- A cyclotron is a cyclic resonant accelerator of heavy particles (protons, ions).



MICROTRON

- electronic cyclotron) is a cyclic resonant accelerator in which, as in the cyclotron, both the magnetic field and the frequency of the accelerating field are constant in time, but the resonance condition in the acceleration process is preserved due to the change in the acceleration ratio.

PHASOTRON

- (synchrocyclotron) - cyclic resonant accelerator of heavy charged particles (for example, protons, ions, α-particles),
- the control magnetic field is constant,
- the frequency of the accelerating electric field varies slowly with a period

The **6 GeV ESRF** is an outstanding example of European cooperation in science. **18** nations work together to use the extremely bright beams of light produced by the ESRF's high-performance storage ring to study a remarkably wide range of materials.

FORCES ACTING ON MOVING CHARGES IN A MAGNETIC FIELD

AMPERE'S LAW

- two conductors with current interact with each other with force:

$$F = k\frac{I_1 I_2}{b}$$

THE MODULE OF THE FORCE ACTING ON THE CONDUCTOR

$$dF = IBdl\sin\left(d\vec{\mathbf{l}}, \vec{\mathbf{B}}\right)$$

$$F_A = I\ell B\sin\alpha$$

WORK OF AMPER FORCE

$$dA = I \cdot (\ell B \cdot dx \cos\alpha)$$

$$dA = I \cdot d\Phi$$

THE RULE OF LEFT HAND

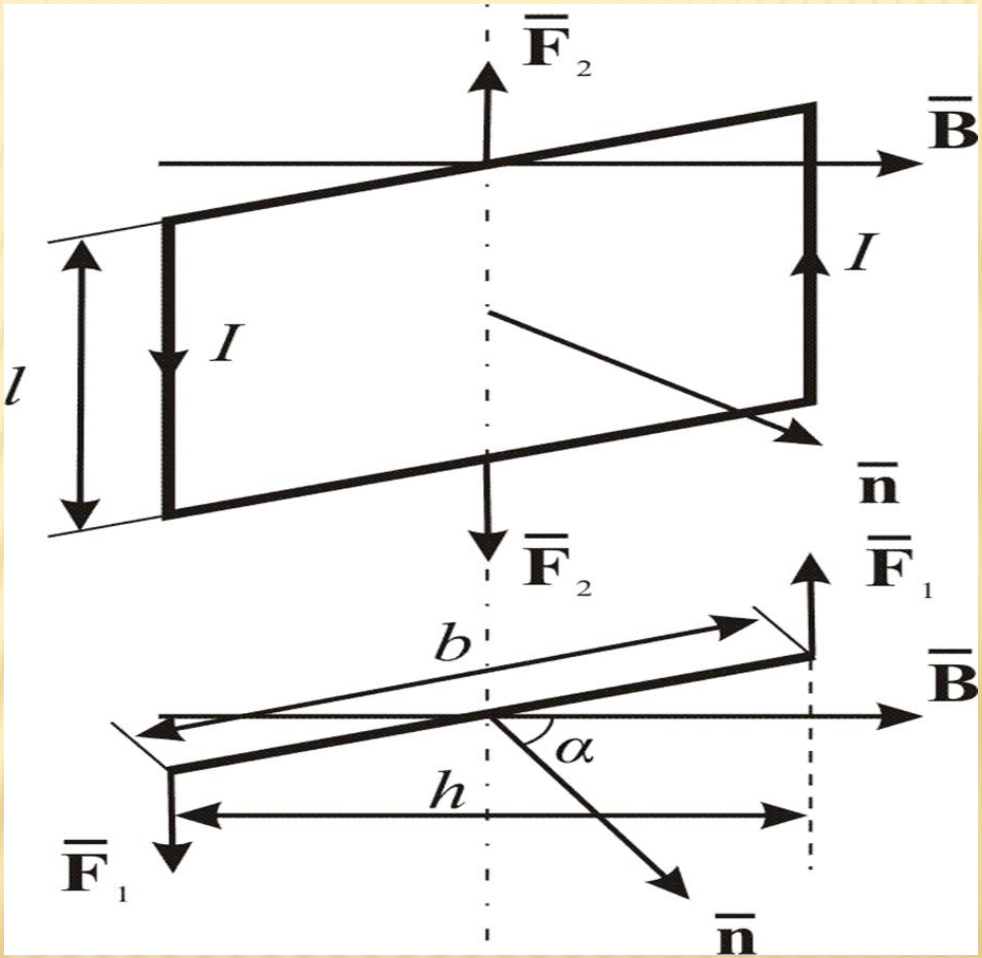
INTERACTION OF INFINITELY SMALL ELEMENTS DL1, DL2 PARALLEL CURRENTS I1 AND I2:

- the currents flowing in the same direction attract each other;
- - currents flowing in different directions are repelled

THE IMPACT OF THE MAGNETIC FIELD ON THE FRAME WITH CURRENT

- The frame with current I is in a uniform magnetic field α - the angle between and (the direction of the normal is connected with the direction of the current by the rule of the cuticle).

THE IMPACT OF THE MAGNETIC FIELD ON THE FRAME WITH CURRENT



MOMENTUM

$$M = IBS\sin\alpha = P_m \sin\alpha$$

MAGNETIC INDUCTION

$$B = \frac{M}{P_m \sin\alpha}$$

MAGNETIC UNITS

- Ampere's law is used to establish the unit of current strength - amperes.

$$\frac{dF}{dl} = \frac{\mu_0}{4\pi}\frac{I_1 I_2}{b}$$

UNITS OF MAGNETIC INDUCTION

$$[B] = \frac{H}{A^2}\frac{A}{м} = \frac{H}{A \cdot м} = 1\,Тл$$

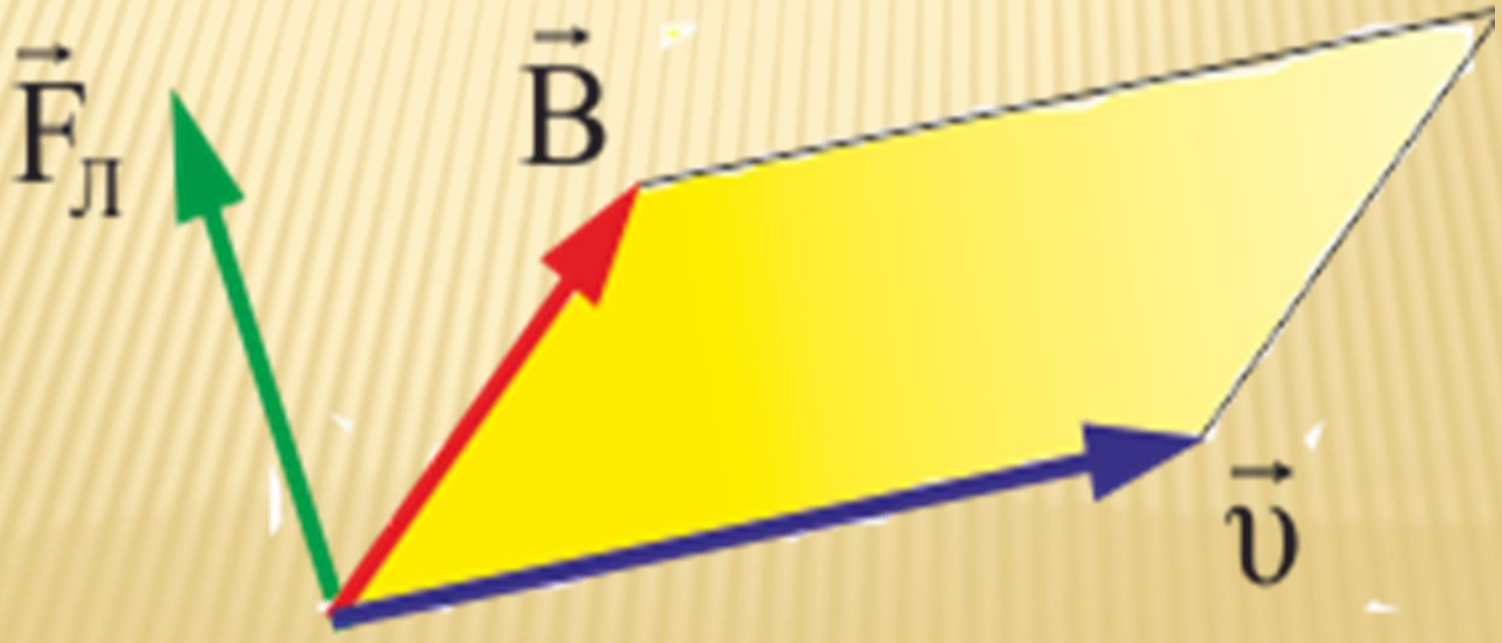
I COULD BRING DOWN BROOKLYN BRIDGE IN AN HOUR

TABLE OF THE MAIN CHARACTERISTICS OF THE MAGNETIC FIELD

Наименование	Обозначение	СИ	СГС	СИ/СГС
Магнитная индукция	*B*		Гс	10^4
Напряженность магнитного поля	*H*	*А/м*	Э	
Магнитная постоянная	μ_0		1	
Поток магнитной индукции	Φ_B	*Вб* (*Тл·м*^{2})	Мкс	10^8

LORENZ FORCE

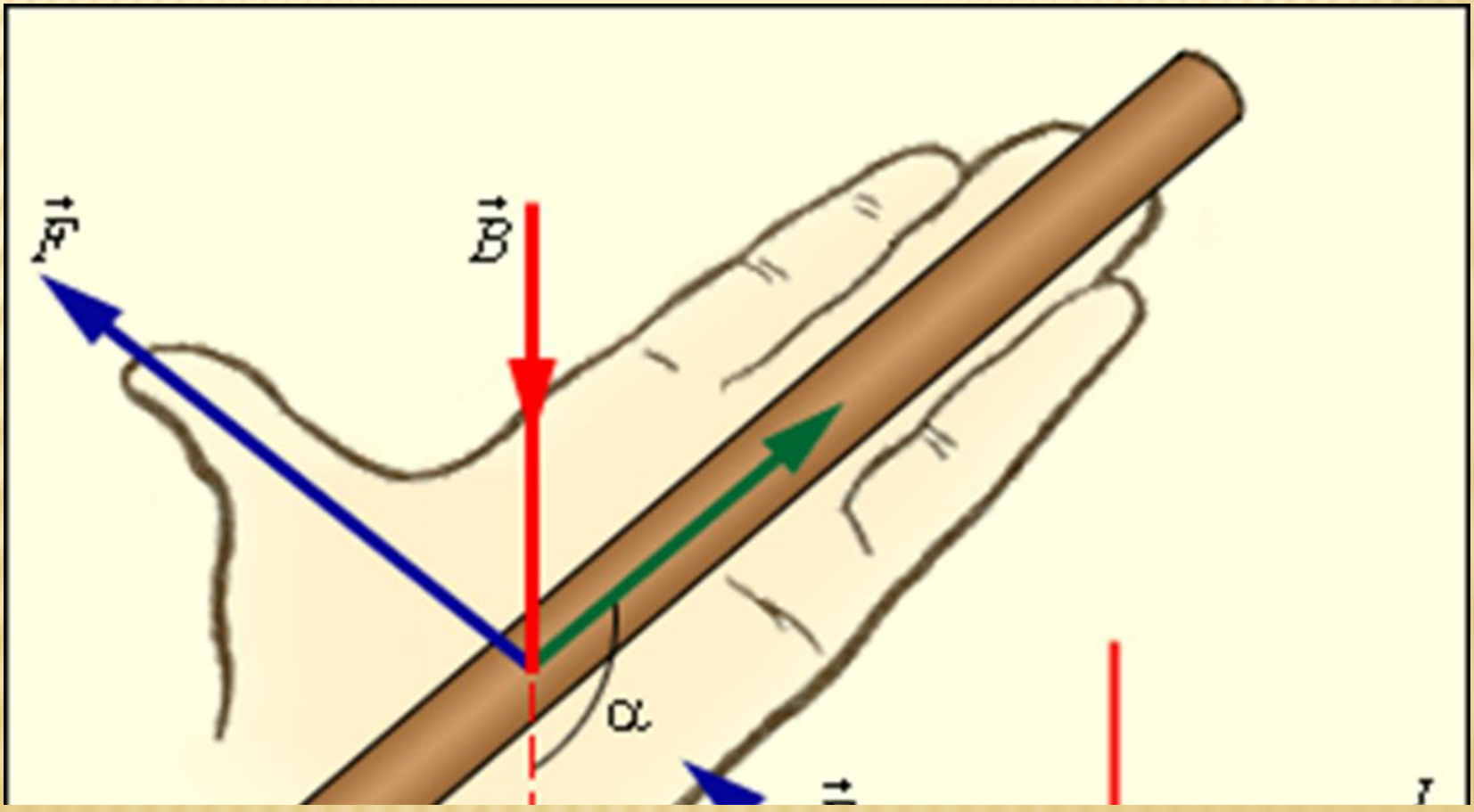
$$\vec{F}_л = q[\vec{\upsilon}, \vec{B}]$$



LORENZ FORCE

$$F_л = q\upsilon B \sin\alpha$$

LORENZ FORCE



OFTEN THE LORENTZ FORCE IS THE SUM OF THE ELECTRIC AND MAGNETIC FORCES:

$$\vec{\mathbf{F}}_{л} = q\vec{\mathbf{E}} + q[\vec{\mathbf{v}}, \vec{\mathbf{B}}]$$

LORENTZ FORCE

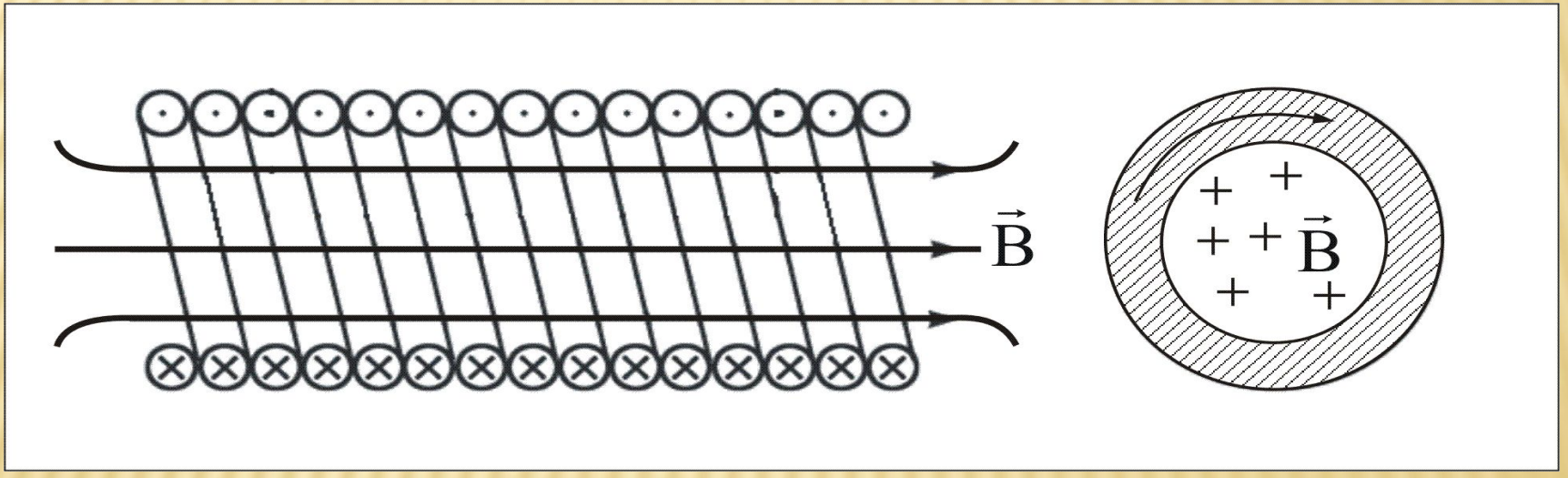
$$F_{Л} = q\upsilon B \sin \alpha$$

REFERENCE

- Lorenz force:
- The total force acting on a charge in an electromagnetic field is
-
- $F = F_E + F_m = qE + q\,[u, B]$.
- The magnetic component of the Lorentz force is perpendicular to the velocity vector, the elementary work of this force is zero.
- Force F_m changes the direction of motion, but not the magnitude of the speed.
-
- The induction of the magnetic field B is measured in SI in tesla (T).
- The element dl of a conductor with current I in a magnetic field is induced by induction B, determined by the Ampere law:
- $dF = I\,[dl, B]$.

SELF-INDUCTION PHENOMENON

- So far, we have considered changing magnetic fields without paying attention to what is their source. In practice, magnetic fields are most often created using various types of solenoids, i.e. multi-turn circuits with current.



SELF-INDUCTION PHENOMENON

- The induced emf arising in the circuit itself is called self-induced emf, and the phenomenon itself is called self-induction.

- If the emf induction occurs in a neighboring circuit, then we speak about the phenomenon of mutual induction.

-

- It is clear that the nature of the phenomenon is the same, and different names - to emphasize the place of origin of the EMF induction.
- The phenomenon of self-induction was discovered by an American scientist J. Henry in 1831.

SELF-INDUCTION PHENOMENON

- The current I flowing in any circuit creates a magnetic flux Ψ that penetrates the same circuit.
- If I change, will change, therefore the induced emf will be induced in the circuit.

- The inductance of such a circuit is taken as the unit of inductance in the SI, in which a full flux $\Psi = 1$ Vb arises at current $I = 1$A.
- This unit is called Henry (Hn).

SOLENOID INDUCTANCE

$$L_{сол} = \mu\mu_0 n^2 V$$

WHEN THE CURRENT IN THE CIRCUIT CHANGES, AN EMF OF SELF-INDUCTION ARISES IN IT, EQUAL TO

$$E_i = -\frac{d\Psi}{dt} = -\frac{d}{dt}(IL) = -L\frac{dI}{dt}$$

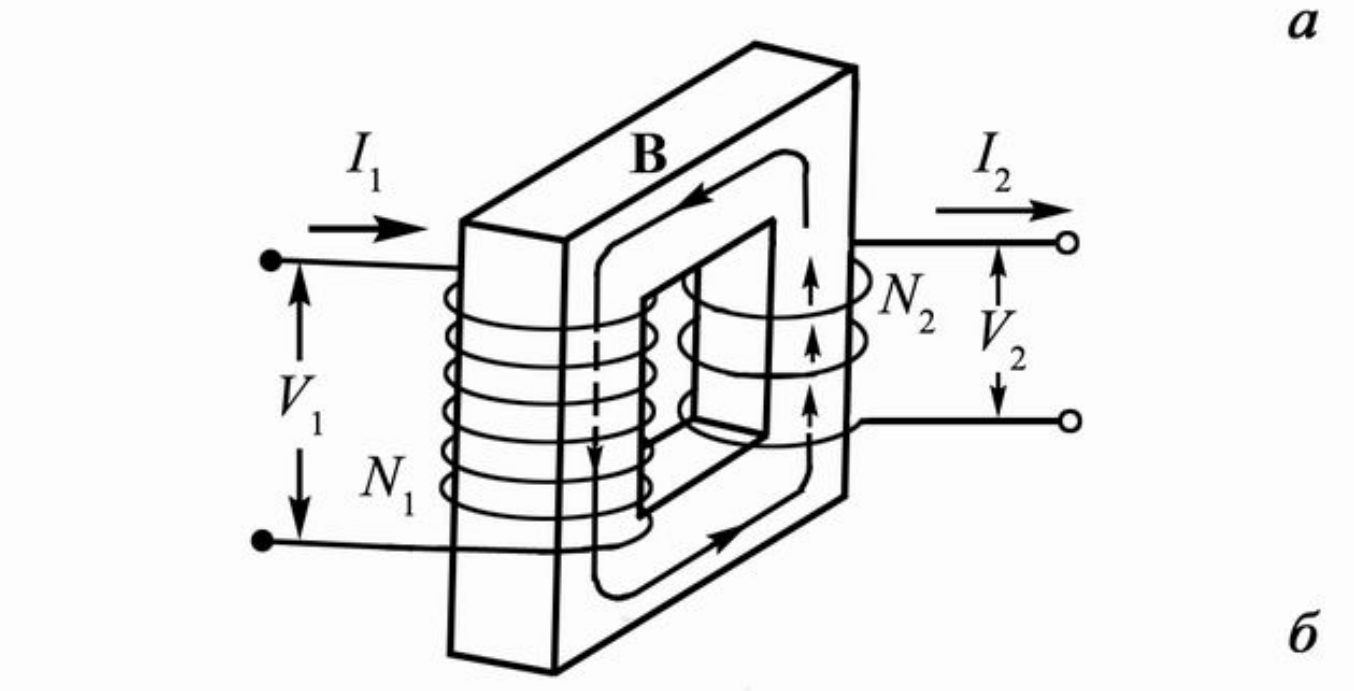
THE MINUS SIGN IN THIS FORMULA IS DUE TO THE LENZ RULE.

$$E_i = -L\frac{dI}{dt}$$

TRANSFORMER INDUCTANCE

- The phenomenon of mutual induction is used in widespread devices - transformers.
- The transformer was invented by Yablochkov, a Russian scientist, in 1876. for separate power supply of separate electric light sources (Yablochkov candle).

TRANSFORMER INDUCTANCE



HEN THE VARIABLE EMF IN THE PRIMARY WINDING

$$E_1 \approx \frac{d(N_1\Phi)}{dt} \approx N_1 \frac{d\Phi}{dt}$$

$$\frac{E_1}{E_2} \approx \frac{N_1}{N_2}$$

TRANSFORMATION RATIO

$$\eta = \frac{E_2}{E_1} = \frac{N_2}{N_1}.$$

ENERGY AND WORK

$$A = \frac{LI^2}{2}$$

DIAMAGNETS AND PARAMAGNETIC IN A MAGNETIC FIELD.

- The microscopic density of currents in a magnetized substance is extremely complex and varies greatly, even within a single atom. But we are interested in the average magnetic fields created by a large number of atoms.
- As it was said, the characteristic of the magnetized state of matter is a vector quantity - the magnetization, which is equal to the ratio of the magnetic moment of a small volume of matter to the value of this volume:

DIAMAGNETS AND PARAMAGNETIC IN A MAGNETIC FIELD.

$$\vec{\mathbf{J}} = \frac{1}{\Delta V} \sum_{i=1}^{n} \vec{\mathbf{P}}_{m\,i},$$

DIAMAGNETISM

- the property of substances to be magnetized towards an applied magnetic field.
- Diamagnetic materials are substances whose magnetic moments of atoms in the absence of an external field are zero, because the magnetic moments of all the electrons of an atom are mutually compensated (for example, inert gases, hydrogen, nitrogen, NaCl, Bi, Cu, Ag, Au, etc.).
- When a diamagnetic substance is introduced into a magnetic field, its atoms acquire induced magnetic moments ΔPm directed opposite to the vector.

PARAMAGNETISM

- the property of substances in an external magnetic field is magnetized in the direction of this field, therefore inside the paramagnetic the action of the induced internal field is added to the action of the external field.
-
- Paramagnetic substances are substances whose atoms have in the absence of an external magnetic field, a nonzero magnetic moment.

PARAMAGNETICS

$$\mu = \frac{B}{B_0} > 1$$

DIAMAGNETICS

$$\mu = \frac{B}{B_0} < 1$$